Studies on Whitefly, *Bemisia tabaci* Genn., Vector of Mungbean Yellow Mosaic India Virus with Special Reference to Seasonal Fluctuation and Virus-Vector Relationship in Soybean

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By

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CERTIFICATE – I

This is to certify that the thesis entitled **"Studies on whitefly, *Bemisia tabaci* Genn., vector of mungbean yellow mosaic India virus with special reference to seasonal fluctuation and virus-vector relationship in soybean"** submitted in partial fulfillment of the requirement for the degree of **DOCTOR OF PHILOSOPHY** in **ENTOMOLOGY** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) is a record of the bonafide research work carried out by **Mr. Rakesh Singh Marabi** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions, J.N.K.V.V., Jabalpur (M.P.).

All the assistance and help received during the course of the investigation has been acknowledged by him.

(Dr. S.B. Das)
Chairman of the Advisory Committee

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I, **Rakesh Singh Marabi** S/o **Mr. P.S. Marabi** certify the work embodied in the thesis entitled "**Studies on whitefly, *Bemisia tabaci* Genn., vector of mungbean yellow mosaic India virus with special reference to seasonal fluctuation and virus-vector relationship in soybean**" is my own first time bonafide work carried out by me under the guidance of **Dr. S. B Das, Professor, Department of Entomology,** College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur during 2012-2019.

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Date: / /2019 **Rakesh Singh Marabi**

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is the world's most important seed legume which contributes 42 per cent of India's total oilseeds and 25 per cent of edible oil production. It has high potential to serve as nutritive food value and a major source of high quality protein (43 per cent), fat (20 per cent), carbohydrate (26.5 per cent) and mineral nutrients (5.5 per cent) (Hymowitz, 1970 and Caldwell, 1973). It is used in the food industry for flour, oil, biscuits, cookies, candy, milk, vegetable cheese, cattle and poultry feed and many other products (Lokuruka, 2010). In the world, United States of America is the major *producer* of soybean and ranks first in production. India ranks fourth in the world in terms of soybean area sown and fifth in production after USA, Brazil, Argentina and China (Agrawal et al. 2013).

In India, during 2015-16 soybean was cultivated in an area of about 11.66 million ha with a production of about 8.59 million tonnes and productivity of 737 kg/ha. Soybean is mainly grown in the states of Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, Andhra Pradesh, Chhattisgarh, Nagaland and Gujarat as a rainfed crop during the rainy (*kharif*) season (Tiwari, 2001). In Madhya Pradesh during 2015-16, it was grown in an area of about 5.91 million ha with a production and productivity of about 4.91 million tonnes and 831 kg/ha, respectively (Anonymous, 2016). Since last few years the productivity of soybean has drastically reduced and is far less than the potential yield of recommended varieties due to severe attack of different insect pests and diseases (Sharma et al. 2014).

About 275 insect species have been recorded attacking soybean crop in India (Salunke et al. 2002). While in Madhya Pradesh, soybean is severely damaged by about a dozen of insect pests on different stages of the crop. Among them stem fly (*Melanagromyza sojae* Zehnt), girdle beetle (*Oberea brevis* Swead), green semilooper (*Chrysodeixis acuta* Walker), tobacco caterpillar (*Spodoptera litura* Fabricius), bihar hairy caterpillar (*Spilosoma oblique* Walker) and whitefly (*Bemisia tabaci* Gennadius) have been recorded as major pests causing severe yield losses to soybean crop (Singh et al. 1989, Choudhary and Shrivastava, 2007 and Sharma et al. 2014). However, whitefly is recognized as an important pest of soybean in India and worldwide (Baldin et al. 2017; Cruz et al. 2016; Biswas, 2013 and Netam et al. 2013). The outbreaks of whitefly (*B. tabaci*) in soybean fields have been reported

during 1972-73 and 1981-82 in Brazil (Kogan and Turnipseed, 1987) and Indonesia (Samudra and Naito, 1991), respectively. In central India (Madhya Pradesh), the outbreaks of whitefly have been reported on soybean crop during 2014-2016 (Gupta and Varma, 2015; Ramesh et al. 2016 and Silodia, 2016). It causes three types of damage in the plants *viz.,* direct damage, indirect damage and transmits viral diseases (Berlinger, 1986 and Pico et al. 1996). Direct *damage* is *caused* by both the nymphs and adults by sucking the sap from the plant foliage. Feeding causes leaf chlorosis, leaf withering, premature dropping of leaves and under heavy feeding pressure it reduces the plant growth and yield (Berlinger, 1986). Whereas the indirect damage is caused by the accumulation of honeydew secreted by the whiteflies which forms a suitable medium for the development of black sooty mould on the leaves and pods. The sooty mould interferes with the photosynthesis activity and decreases the yield and market value of the crop (Byrne and Bellows, 1991; Hendrix et al. 1992; Jones, 2003; Mugiira et al. 2008 and Mann et al. 2009).

The whitefly plays an important role as a vector for many viral diseases. The whitefly-transmitted viruses produce a wide range of symptoms on leaves *viz.,* vein yellowing, yellow *blotching*, yellow mosaic, *curling, crumpling, vein thickening, leaf enations,* leaf cupping and plant *stunting (*Muniyappa and Veeresh, 1984 and Duffus, 1987). The whitefly transmitted viruses belong to the genus Begomovirus and family Geminiviridae. Geminiviridae ranks as the second largest family of plant viruses and more than 80 per cent of the known geminiviruses are transmitted by whiteflies and is represented by four genera: Mastrevirus, Curtovirus, Topocuvirus and Begomovirus (Costa, 1976 and Brown et al. 1995). The genus Begomovirus comprises of circular single-stranded DNA genomes which contain bipartite DNA-A and DNA-B. DNA-A encodes the coat protein which is associated with the replication and transcription activation, while DNA-B component is involved in virus movement (Harrison and Robinson, 1999; Lazarowitz and Shepherd, 1992; Varma and Malathi, 2003; Fauquet et al. 2008 and Varma et al. 2011).

The first record of whitefly-transmitted virus which caused yellow mosaic disease (YMD) on soybean and mung (*Phaseolus aureus* L.) was reported in 1935 and 1955 from USA (Pierce, 1935) and India (Nariani, 1960), respectively, since then it had spread in alarming proportions. The disease

symptoms initially appear on the young leaves in the form of mild scattered yellow specks or spots. The infected plants usually mature late and bear very few flowers, reduced size pods and eventually small size seeds are obtained (Nene, 1973; Costa et al. 1973; Suteri, 1974 and Varma et al. 1992).

On the basis of molecular studies two species of begomoviruses *viz.,* Mungbean yellow mosaic India virus (MYMIV) and Mungbean yellow mosaic virus (MYMV) have been identified and characterized to cause YMD in legumes (soybean, blackgram and mungbean) in India. The MYMIV is severely prevalent in the northern and central and the MYMV in the southern and western Indian region (Morinaga et al. 1990; Mandal et al. 1997; Usharani et al. 2004; Malathi, 2007; Qazi et al. 2007; Khan et al. 2013 and Ramesh et al. 2016).

In India, YMD of soybean initially was reported from the northern region, later it had spread to different parts of central India, where large acreage is under soybean cultivation resulting in yield losses ranging from 10-88% (Sanger, 1988 and Dantre et al. 1992). The monetary losses in legumes caused by YMD have been estimated to be approximately US$ 300 million per annum (Varma et al. 1992). In Madhya Pradesh, MYMIV have been identified to cause YMD which is most prevalent and has been found to be one of the major constraints in soybean production (Ramesh et al. 2013 and Ramesh et al. 2016). The upsurge *of* whitefly *(B. tabaci)* population and incidence of YMD in central India (Madhya Pradesh) caused soybean yield losses which ranged from 10-90% (Dasgupta et al. 2003 and Gupta and Keshwal, 2003).

In the past decade due to modern agricultural practices such as intensive and extensive farming, nonjudicious application of fertilizers and pesticides, rendered the prevalence and distribution of whitefly-transmitted plant viruses on legume crops (Matson et al. 1997; Morales and Anderson 2001; Varma and Malathi 2003; Xie and Zhou 2003; and Seal et al. 2006). The aggregated distribution of *B. tabaci* on the legume crops during the summer and *kharif* seasons cause severe yield losses throughout the world (Rathore and Tiwari, 1998).

Adequate base line information is a prerequisite for understanding the outbreaks of whitefly vector and YMD. Studies on virus (MYMIV)-vector relationship have not been carried out systematically on soybean crop, only a

small portion of acquisition and inoculation access periods have been elucidated by earlier workers (Usharani et al. 2005; Yadav et al. 2009; Gazala et al. 2013 and Yadav et al. 2015).

Due to climate change coupled with outbreak of whitefly infestation and incidence of YMD, there is a detrimental effect on the soybean production. As a result the policy makers and seed suppliers are not able to cater sufficient soybean seeds to the farmers for the forthcoming *kharif* seasons. The farmers are compelled to grow *rabi* and summer soybean crops to fulfill the soybean seed demand. In context to the above situation an experiment was conducted to grow soybean round the year *i.e. rabi*, summer and *kharif* season to study the status of whitefly and YMD infection.

For developing weather based forecasting model, information on seasonal incidence of whitefly and YMD in relation to prevalent weather parameters are as the same weather parameters also influence the growth and development of the crop. Similarly influence of weather factors on pest population and disease intensity differs from region to region. Thus, sufficient understating about the seasonal activity of whitefly, incidence of YMD and relationship between virus (MYMIV)-vector (*B. tabaci*) is necessary for formulating pest management strategies which should be socially acceptable and economically feasible in a particular region.

Keeping in view the above facts, the present research work was carried out with the following objectives:

1. To study the seasonal incidence of whitefly and yellow mosaic disease in soybean crop.
2. To study the presence of MYMIV in whitefly and soybean plant through molecular technique.
3. To study the virus (MYMIV)-vector (*B. tabaci*) relationship in soybean in insect proof net house.

REVIEW OF LITERATURE

The present investigation entitled "Studies on whitefly, *Bemisia tabaci* Genn., vector of mungbean yellow mosaic India virus with special reference to seasonal fluctuation and virus-vector relationship in soybean" had been reviewed and presented in this chapter. The literature available pertaining to mungbean yellow mosaic India virus on soybean which is a whitefly transmitted begomovirus is scanty, hence whitefly transmitted Geminiviruses on different pulses, vegetables and fibre crops are also reviewed for the support of the present investigation.

2.1 To study the seasonal incidence of whitefly and yellow mosaic disease in soybean crop

Murugesan and Chelliah (1977) recorded maximum incidence of mungbean yellow mosaic virus (MYMV) on summer mungbean crop during March to May while low incidence was observed in the crop raised from August to December under south Indian conditions. The increased disease incidence might be attributed to higher temperatures prevalent during these months, which was also favourable for the vector, *Bemisia tabaci* to develop and multiply.

Sharma et al. (1987) studied the influence of temperature and wind speed on the incidence of yellow vein mosaic virus (YVMV) transmitted by *Bemisia tabaci* in okra. They revealed that maximum and minimum temperature and wind velocity had exhibited significant negative correlation with incidence of YVMV.

Borad (1991) studied population dynamics of whitefly, *B. tabaci* on tomato and okra and revealed that maximum temperature and sunshine hours had positive impact on whitefly population.

Sahoo and Sahu (1991) found positive correlation between whitefly population and incidence of yellow mosaic virus (YMV) in urdbean crop.

Nath (1994) studied the relationship between yellow mosaic disease (YMD) incidence and population size of whitefly, *B. tabaci* on mungbean. He reported that whitefly population, temperature, relative humidity (RH), rainfall

and number of rainy days had significant positive impact on the disease incidence.

Singh et al. (1994) recorded whitefly population on cotton in Punjab from 1992-1994. They reported that it ranged from 0.42-12.27, 1.08-30.47 and 0.50-185.40 whiteflies/3 leaves and attained peak in the third week of October (*i.e.* 42nd SW), second week of October (*i.e.* 41st SW) and fourth week of October (*i.e.* 43rd SW) during first, second and third year, respectively. Further, the incidence of cotton leaf curl virus disease (CLCV) ranged from 1.5-91.4% on different American cotton varieties.

Singh and Kalra (1995) studied whitefly incidence and YMD infection on mungbean and urdbean crops and reported that it ranged from 0.05-6.65 and 0.05-19.25 adults per plant, 10-21.25 and 7.5-17.50%, respectively. The peak population of the pest was observed during May end, when the temperature and RH were 32^{0}C and 22%, respectively. Maximum temperature and RH had significant positive and negative correlation with whitefly population, respectively.

Sharma et al. (1997) reported that mean temperature around 26^{0}C was most conducive for the population build-up of whitefly, *B. tabaci* on soybean and showed significant positive correlation with mean temperature and sunshine while negative correlation with rainfall.

Rathore et al. (1998) studied the incidence of whitefly on urdbean and recorded an overall seasonal mean of 14.25 whiteflies/cage. Morning and evening RH had significant negative while maximum and minimum temperature had positive correlation but statistically found to be non-significant, with whitefly population.

Akbar et al. (2000) recorded whitefly population on soybean upto eight weeks in autumn (*kharif*) 1998 and ten weeks in spring (*rabi*) 1999. They reported that in autumn, the whitefly population greatly fluctuated due to rains while in spring there was a constant increase in the population. Average seasonal pest population recorded was 0.57 and 0.21 whitefly/leaf during autumn and spring season, respectively.

Kumawat et al. (2000) studied the seasonal incidence of whitefly population on okra and their correlation with abiotic factors during *kharif* in the semi-arid region of Rajasthan. They reported that infestation of whitefly started from fourth week of July and reached its peak in the second and fourth week of September. Maximum temperature had significant positive correlation with whitefly population.

Chaudhuri et al. (2001) studied the seasonal abundance of whitefly (*B. tabaci*) on tomato crop and reported that it attained its peak (1.68 whitefly/plant) during mid-February and it continued up to mid-March, when temperature, RH, sunshine and rainfall ranged from 17.07-22.13^{0}C, 65.29-72.78%, 7.79-9.98 hr/day and 5mm, respectively. They also reported that the temperature, RH and rainfall had significant negative influence on whitefly population.

Dar et al. (2002) reported that occurrence of whitefly started from 16th SW (*i.e.* 22nd to 28th April) and remained available upto 26th SW (*i.e.* 01st to 07th July) on summer mungbean and from 16th SW to 25th SW (*i.e.* 24th to 30th June) on summer urdbean, respectively. The whitefly population reached its peak in the 25th and 26th SW in urdbean (31 whiteflies/plant) and mungbean (32 whiteflies/plant), respectively. Thereafter there was a gradual decrease in the pest population, but was available up to the crop maturity stage.

Gupta and Keshwal (2002) observed that the rate of development of YMV disease transmitted by whitefly on soybean was maximum when maximum temperature and RH ranged between 31.00^{0}C to 36.20^{0}C and 62.00 to 75.00%, respectively.

Dangar (2003) reported that the first incidence of whitefly on fenugreek crop was observed during 3rd week of November (*i.e.* 4 weeks after sowing) and attained peaks during 3rd week of December and 2nd week of January (*i.e.* 8 and 11 weeks after sowing, respectively).

Gupta and Keshwal (2003) reported that the rate of disease incidence of YMV on soybean was maximum when the maximum temperature and RH ranged between 29.90^{0}C to 36.20^{0}C and 62-75%, respectively. The disease spread was fast during 30-60 days after sowing (DAS) of the crop. The

disease development at 50 DAS showed significant positive correlation with maximum temperature and sunshine hours and negatively associated with evening RH, wind velocity and total rainfall. Chandra and Rajak (2004) conducted studies on insect pests of urdbean and reported that the whitefly was first observed in the second week of September (*i.e.* 37th SW) (1.6 whiteflies/ plant) and reached its peak in the first week of October (*i.e.* 40th SW) (13.2 whiteflies/ plant).

Kumar et al. (2004) recorded peak population of whitefly in mungbean and urdbean during first fortnight of May in summer and second fortnight of September in *kharif* season, respectively. Temperature and sunshine hours had significant positive correlation with whitefly population.

Sharma and Rishi (2004) reported a positive association between whitefly population of CLCV disease in cotton. The whitefly population, morning RH and sunshine had significant positive while maximum and minimum temperature and wind velocity had significant negative influence on the disease incidence.

Sharma and Rishi (2004a) reported that the first appearance of whitefly (*B. tabaci*) on cotton was observed during first week of June and was available upto end of September and was maximum between mid August to end of September. RH and sunshine hours had significant positive correlation, while maximum temperature, rainfall and wind velocity expressed negative association with whitefly population but statistically found to be non-significant.

Bharadiya and Patel (2005) studied the succession of insect pests on brinjal during *kharif* 2002 at Gujarat, India and stated that the activity of whitefly, *B. tabaci* was maximum during the fourth week of October (*i.e.* 43rd SW).

Bhatnagar and Dahiya (2005) reported that during *kharif* season the whitefly population ranged from 19.4 to 38.1 and 25.3 to 62.2 whiteflies/plant, whereas YMD incidence ranged from 1.4 to 47.1% and 1.8 to 33.0% in mungbean and urdbean, respectively.

Safdar et al. (2005) reported that minimum temperature and RH had significant positive impact on whitefly population on okra. Whereas, minimum temperature, RH and wind velocity exhibited significant positive influence on okra YVMV.

Muhammad et al. (2006) conducted studies on population dynamics of whitefly on cotton. The first incidence of whitefly was observed during 3rd week of July and it remained available upto 2nd week of October and reached its peak during 4th week of August and 1st week of September. Temperature and RH exhibited significant positive impact on whitefly population while rainfall showed positive correlation, but statistically found to be non-significant. However, R value computed through multivariate regression analysis expressed that temperature, humidity and rainfall collectively showed 66.4% influence on the whitefly population fluctuation.

Patil (2006) studied the seasonal abundance of whitefly on mungbean during *rabi* 2004. Peak population of whitefly (2.12 whiteflies/ leaf) was observed in the 5th week of October *i.e.* 8 weeks after sowing (WAS). Maximum temperature and sunshine had significant positive and negative correlation with whitefly population. Whereas in summer 2015, whitefly population (1.82 whiteflies/ leaf) reached its peak in the 3rd week of April (*i.e.* 8 WAS). During this cropping season, maximum and minimum temperature had positive while sunshine had negative impact on whitefly population, but statistically found to be non-significant.

Barfa (2007) studied the seasonal incidence of whitefly on tomato and reported that it appeared during the last week of December and remained active upto the crop maturity stage. The peak population was observed during first week of February when maximum and minimum temperature was 29.2^{0}C and 13.4^{0}C, respectively with 87% evening RH and no rainfall.

Kooner and Harpreet (2007) studied consecutively for four years on the incidence of whitefly and MYMV on mungbean during *kharif* season and reported that overall mean population and MYMV disease intensity grade ranged from 1.21 to 9.63 whiteflies/plant and 0.25 to 3.34%, respectively.

Kumar et al. (2007) studied the seasonal incidence of whitefly a major pest of mungbean and reported that maximum temperature, RH and rainfall showed positive correlation with whitefly population, however the values were non-significant.

Acharya and Bhargava (2008) studied the incidence of whitefly, *B. tabaci* on cotton. They reported that the first incidence of whitefly was observed in the last week of June. Initially the population was very low but it increased gradually and reached its peak (147.10 nymph and adult whiteflies/3 leaves) in the last week of September (*i.e.* 40^{th} SW) and gradually declined, but was available up to the crop maturity.

Ahirwar (2008) studied the seasonal abundance of whitefly on mungbean and reported that the first appearance was observed during 3^{rd} week of March and remained active till the crop was harvested. The peak population (3.81 whiteflies/ 6 leaves) was observed during the 4^{th} week of April *i.e.* 20^{th} to 26^{th} April when the maximum and minimum temperature were 41.9^0C and 19.8^0C, respectively with 43% morning and 9% evening RH and no rainfall. Wind speed was found to be significant and negatively correlated with whitefly population.

Bhatt (2008) reported that whitefly, *B. tabaci* first appeared on soybean (*Glycine max*) when the crop was 30 days old *i.e.* 7^{th} August, 2006.

Chandrakumar et al. (2008) recorded the seasonal occurrence of whitefly, *B. tabaci* on brinjal at College of Agriculture, Bangalore during *rabi* 2005. They reported that the first incidence of whitefly was observed during 3^{rd} week of December, while maximum temperature and rainfall showed negative significant correlation with whitefly population.

Prasad et al. (2008) studied the population dynamics of major sucking pests infesting cotton and revealed that the peak incidence of whitefly was recorded from 44^{th} to 48^{th} SW (November). Maximum and minimum temperature and rainfall had negative correlation, but statistically non-significant with whitefly population.

Puneet et al. (2008) studied the population dynamics of whitefly, *B. tabaci* on mungbean and reported that temperature and relative humidity

exhibited significant positive while rainfall had negative association with whitefly population.

Rafiq et al. (2008) studied the population dynamics of whitefly (*B. tabaci* Gen.) throughout the year for 6 consecutive years on oilseed, pulses, sugar, fodder and vegetable crops in cotton growing areas of Punjab, Pakistan. Infestation based on their abundance was found on 17 field and 28 vegetable crops. They further reported that spring vegetables *viz., Citrullus* spp., *Cucumis* spp. *Solanum* spp. and pulse, *Glycine* max, mainly helped in the pre-cotton season build up of whitefly population in addition to early sown cotton.

Naik et al. (2009) studied the seasonal incidence of *B. tabaci* on brinjal and reported that it attained peak during the 3rd week of February 2006. Minimum temperature and morning RH exhibited positive while maximum temperature, evening RH and rainfall had negative association with whitefly population, but statistically non-significant.

Salam et al. (2009) observed that there was an increase in the whitefly population on mungbean with the increase in the crop age *i.e.* 5.43, 7.00, 6.90 and 7.00 whiteflies/3 leaves at 44, 50, 59 and 65 days after planting while the mean MYMV disease incidence recorded on the crop at 75 days after planting was 49.19%.

Shivanna et al. (2009) reported that whitefly population reached at its peak in the second fortnight of April (29.50 whiteflies/3 leaves) on cotton. Thereafter the population declined during July and August months. Maximum temperature had significant positive while minimum temperature, RH and rainfall had positive and negative correlation, respectively with whitefly population, but statistically found to be non significant.

Singh et al. (2009) studied incidence of Dolichos yellow mosaic virus (DYMV) transmitted by whitefly, *B. tabaci* on Indian bean during the years 2006-07 and 2007-08. They reported that during both the years, environmental factors like temperature and RH played an important role on incidence of DYMV. When the temperature ranged between 26.90-35.30^{0}C

and 10.40-16.20^{0}C with RH of 72-74%, DYMV incidence reached its peak *i.e.* more than 80%.

Sitaramaraju et al. (2010) reported that on *Bt* cotton the population of whitefly was low throughout the season and reached at its peak in the 46th SW. Morning RH had significant positive while maximum and minimum temperature had significant negative impact on the whitefly population. Further higher temperature was found conducive for rapid multiplication and activity of whitefly. Multiple linear regression analysis revealed that all the weather parameters together were responsible for 66.1% (R^2 value) variation in whitefly population on *Bt* cotton.

Abd El Samed et al. (2011) reported that whitefly, *B. tabaci* was the most abundant pest on soybean which attained two peaks during the year 2009 and 2010. The first and second peaks occurred in the 1st week of July and 2nd week of August, respectively during both the years of study. RH had significant positive while, maximum and minimum temperature had positive correlation with whitefly population but statistically found to be non significant in the first year. Whereas, in the second year maximum temperature had significant positive while minimum temperature and RH had positive correlation, but statistically found to be non significant.

Mane and Kulkarni (2011) studied the population dynamics of whitefly, *B. tabaci* on brinjal. The incidence of whitefly started in the 32nd SW and continued upto 43rd SW and attained two peaks. The first peak was recorded during 38th SW and the second peak during 40th SW. Correlation studies revealed that the morning RH and rainfall had significant positive impact, while maximum and minimum temperature, evening RH, number of rainy days, sunshine, evaporation and wind velocity had positive influence on whitefly population, but statistically found to be non significant. Further, computation of path analysis revealed that number of rainy days exhibited highest positive direct effect while evening RH showed highest negative direct effect on the whitefly population.

Panduranga et al. (2011) reported that on 40 days old mungbean crop the mean whitefly population was 9.55 whiteflies/ 5 plant, whereas the MYMV incidence was 40%.

Salam et al. (2011) conducted a roving survey to study the status of MYMV disease incidence in mungbean (*Vigna radiata* L.) spread over various taluks of Dharwad, Gadag, Haveri, Gulbarga and Bidar districts of Karnataka state. They reported that the disease incidence ranged from 2.61-22.64%.

Singh and Kumar (2011) reported that the maximum population of whitefly (18.50/plant) on urdbean was in the 39th SW. During this week, maximum and minimum temperature, RH and rainfall were 31.60^{0}C, 24.80^{0}C, 81.90% and 2.00 mm, respectively. However, from 40th SW there was a gradual decline in the pest population. The minimum temperature and RH showed positive whereas, maximum temperature and rainfall expressed negative correlation with whitefly population, but statistically non-significant.

Singh et al. (2011) studied the epidemiology of a *B. tabaci* transmitted Tomato leaf curl virus disease on tomato for two consecutive years 2005 and 2006. They reported that the disease incidence ranged from 5.33-78% and 3.67-80.00% during 1st and 2nd year, respectively. During both the years, maximum temperature and RH had exhibited significant positive and negative association with the disease incidence.

Gopalaswamy et al. (2012) recorded maximum population of adult whitefly (33.33 whiteflies/5 plants) on urdbean at 50 days after sowing (DAS) during the *rabi* season whereas, the incidence of YMD recorded was 38.3 and 58.3% at 60 and 80 DAS, respectively.

Khan et al. (2012) studied the epidemiology of MYMV on mungbean and reported that minimum temperature, RH and rainfall had significant positive while maximum temperature had negative influence on the disease incidence, but statistically found to be non-significant.

Selvaraj and Ramesh (2012) studied the seasonal abundance of whitefly on cotton and reported that whitefly appeared from first week of March *i.e.* on five weeks old crop and reached its peak in the fourth week of July *i.e.* on thirteen weeks old crop. Maximum pest population (7.99 whiteflies/3 leaves) was observed when the temperature ranged from 26^{0}C-35^{0}C, RH ranged from 67-84%, wind velocity 6.30 km/hr, sunshine 9.4 hrs, evaporation 52.20 mm and dewfall 0.708 mm with no rainfall. Maximum and

minimum temperature exhibited significant positive whereas, evening RH had significant negative impact on whitefly population.

Srivastava and Prajapati (2012) studied the influence of weather parameters on whitefly infesting urdbean in Tikamgarh district of Bundelkhand Agro-climate zone. They reported that maximum temperature had significant positive, while morning and evening RH and rainfall had significant negative association with whitefly population. Whereas, rainfall had significant negative influence on the incidence of MYMV.

Biswas (2013) studied the seasonal abundance of whitefly and epidemiology of YMV on soybean during *rabi* 2010 and 2011. He reported that the whitefly population and YMV incidence ranged from 4.00 to 5.00 and 3.00 to 3.50 whiteflies/ plant and 95 and 100% during 2010 and 2011, respectively. High vector population and YMV disease incidence in both the years may be due to high temperature, coupled with low RH and rainfall, might have provided suitable conditions for the build-up of the vector population.

Khan et al. (2013) reported soybean cv. JS 335 to be susceptible to YMD as it recorded 30.96% disease incidence at Ghaziabad during the *kharif* 2008 and further emphasized that it is one of the major viral diseases of *rabi* / summer soybean in Uttar Pradesh.

Netam et al. (2013) reported whitefly as the major pest of soybean causing damage at various stages of the crop. The mean whitefly population ranged from 1.3 to 3.6 whiteflies / plant and reached its peak during 3rd week of September. During this period, maximum and minimum temperature, morning and evening RH and rainfall were 32.20^{o}C, 24.50^{o}C, 92.00%, 64.00% and 51.00 mm, respectively. The maximum temperature and morning RH exhibited positive while minimum temperature, evening RH and rainfall had negative correlation with whitefly population, but statistically found to be non significant.

Nitharwal (2013) reported that the incidence of whitefly on mungbean during 2006 and 2007 commenced from first week of August and were available throughout the crop season. The infestation reached its peak in the

36th SW (10.80 whiteflies/ 3 leaves) in the first year, when the maximum and minimum temperature and RH were 31.70^{0}C, 22.90^{0}C and 76.00%, respectively. Whereas, in the second year, it attained peak in the 37th SW (11.20 whiteflies/3 leaves). During this period the maximum and minimum temperature and RH were 32.10^{0}C, 22.50^{0}C and 69.50%, respectively. Correlation studies revealed that RH exhibited significant positive while, maximum temperature had significant negative correlation with whitefly population.

Sharma et al. (2013) studied the seasonal incidence of whitefly, *B. tabaci* on tomato (cv. Pusa Ruby) and reported that the pest was first noticed in the 14th SW and the population increased gradually and attained its peak in the 21st SW. Maximum temperature exhibited significant positive, while morning and evening RH had significant negative influence on whitefly population. Further, rainfall had exhibited negative correlation, but statistically found to be non-significant. Computation of multiple linear regression analysis showed that all the above weather parameters were together responsible for 89% (R^2 value) variation in whitefly population.

Yadav (2013) reported that the first appearance of whitefly on soybean was observed during 33rd SW (1.6 whiteflies/ 3 leaves/ plant) with slight fluctuation and attained its peak (6.1 whiteflies/3 leaves/ plant) during 39th SW. During this period maximum and minimum temperature were 33.70^{0}C and 21.80^{0}C, respectively, whereas morning and evening RH were 93.40% and 51.90%, respectively, with no rainfall. After 39th SW, there was a sudden decline in the whitefly population and it decreased to 3.3 whiteflies/3 leaves/plant in the 40th SW. During this period, maximum and minimum temperature were 34.30^{0}C and 20.00^{0}C, respectively, whereas morning and evening RH were 85.00% and 38.40% respectively, with no rainfall. Maximum temperature and evaporation had significant positive, while evening RH and rainfall had significant negative correlation with whitefly population. However, minimum temperature exhibited negative and morning RH expressed positive correlation with whitefly population, but statistically found to be non-significant.

Raghuvanshi et al. (2014) studied the population dynamics of whitefly on soybean (cv. JS 95–60) in Gird region during *kharif* 2011. The activity of

whitefly started at 14 days after sowing (DAS) and reached its peak in the first week of August *i.e.* at 35 DAS and remained available upto first week of September (*i.e.*70 DAS). During the peak period maximum and minimum temperature, RH and rainfall were 31.50^{0}C, 25.30^{0}C, 92.10% and 71.80mm, respectively.

Sharma and Kumar (2014) studied the seasonal abundance of whitefly on cotton and reported that the insect pest attained peak in the 42nd SW and thereafter its population declined and remained available upto 51st SW. Morning RH and sunshine had significant positive, while maximum and minimum temperature, RH and rainfall had negative correlation with whitefly population, but statistically found to be non-significant.

Ahirwar et al. (2015) studied the seasonal activity of whitefly on soybean (cv. JS 335) during *kharif*, 2012 and recorded its first appearance on 30th July, 2012 (31st SW) (*i.e.* 20 DAS) and it remained available upto second week of October (*i.e.*41st SW). The pest attained its first peak (3.1 whiteflies/ plant) in the 33rd SW and second peak (3.2 whiteflies/ plant) in the 35th SW.

Deole (2015) studied the seasonal incidence of whitefly on brinjal and found that the activity of insect pest initiated in the first week of April (6.33 whiteflies/ plant). During this period the maximum and minimum temperature and morning RH were 35.94°C, 20.78°C and 75.00%, respectively. The peak activity of the pest was observed during first week of May, when maximum and minimum temperature and RH were 25.00°C, 40.00°C and 55.00%, respectively. The correlation studies between whitefly and different weather parameters were found to be non significant.

Gaur et al. (2015) studied the population dynamics of whitefly on soybean during *kharif* 2012-13. They observed that whitefly appeared at the early crop stage *i.e.* 2 weeks after sowing (WAS) (29th SW *i.e.* 3rd week of July 2012) and remained active up to the maturity of the crop. The first peak was observed during 33rd SW (2nd week of August 2012) *i.e.* 42 WAS and second peak was observed during 36th SW (1st week of September 2012) *i.e.* 63 WAS. Minimum temperature, morning and evening RH, rainfall and wind velocity had exhibited positive while maximum temperature, sunshine and

evaporation had negative correlation with whitefly population, but statistically found to be non-significant.

Gupta and Varma (2015) studied the epidemiology of YMD on soybean (cv. JS 335). They reported that the rate of disease development was high (42-59%) when the maximum temperature and RH ranged between 29.9^{0}C to 36.2°C and 62 to 75 %, respectively coinciding with the vulnerable stage of the crop (30-45 DAS).

Kalkal et al. (2015) studied the seasonal abundance of whitefly on cotton and reported that maximum and minimum temperature, wind speed, evening RH and sunshine showed significant positive while morning RH and rainfall had significant negative influence on the pest population.

Yadav et al. (2015) studied the seasonal fluctuation of whitefly on soybean and reported that the pest first appeared on 13th July (*i.e.* 7 days after germination (DAG)) and remained available up to 21st September *i.e.* 77 DAG. The population reached its first peak on 27th July (6.7 whiteflies/ plant) and second peak (8.4 whiteflies/ plant) on 10th August. The maximum temperature and RH prevailed during this period was found to be favourable for the pest (*i.e.,* 32-32.5^{0}C and 78-79%, respectively). Thereafter, the pest population gradually decreased and remained available upto 3rd week of September *i.e.* 77 DAG and disappeared in the 4th week of September.

Kumar et al. (2016) studied the population dynamics of whitefly on mungbean and reported its first appearance during 15th SW which continued up to 22nd SW. Peak population (2.88 whiteflies/10 cm twig) was recorded during 20th SW, thereafter it gradually declined. Morning RH and morning vapour pressure had significant negative while maximum and minimum temperature, sunshine and evaporation had positive correlation with whitefly population, but statistically found to be non significant.

Kumar and Singh (2016) carried out studies on seasonal abundance of whitefly on urdbean. They reported that the pest first appeared during 34th SW and remained available up to 39th SW. The peak population (8.07 whiteflies/ cage/ plant) was observed during 37th SW. Morning RH had significant positive impact on whitefly population. While, evening RH and rainfall had

positive whereas maximum and minimum temperature and sunshine had negative influence on whitefly population, but statistically non significant.

Muhammad et al. (2016) conducted a survey on whitefly population fluctuation on sunflower for two years on vegetable fields of Tandojam and Sultanaabad in Sindh, Pakistan. They reported that the whitefly population initiated from 2nd week of January and reached its peak (17.77±0.78 whiteflies/5 leaves/ plant) in the 2nd week of April (14th SW) at Tandojam. While at Sultanaabad, it initiated from 1st week of January and attained its peak (25.92±0.66 whiteflies/5 leaves/ plant) in the 3rd week of April (16th SW). Correlation studies revealed that temperature and RH had significant positive effect on whitefly population.

Silodia (2016) observed the incidence of whitefly on soybean (cv. JS 335), and reported that it commenced from 1st week of July, 2015 (27th SW), during this period, maximum and minimum temperature was 29.80^{0}C and 23.60^{0}C, respectively while morning and evening RH and rainfall were 90.00%, 70.00% and 149.40 mm, respectively. The population of whitefly reached its peak (7-25 whiteflies/ leaf) during 35th SW. During peak population of whitefly, maximum and minimum temperature, morning and evening RH, rainfall and sunshine were 30.40^{0}C and 22.90^{0}C, 93.00%, 76.00%, 104.60 mm and 3.00 hrs, respectively. The incidence of MYMIV on the crop was first noticed on 7th August, 2015 (32nd SW) which reached 60% in the 3rd week of August (34th SW). During this period, maximum and minimum temperature was 31.20^{0}C and 24.20^{0}C, respectively, while morning and evening RH, rainfall and sunshine were 91.00%, 79.00%, 14.00mm and 4.60 hrs, respectively. Thereafter, within a short period of time (10-15 days), the disease spread rapidly and infected more than 90% foliage of the soybean crop.

Srinivasaraghavan et al. (2016) studied the incidence of mungbean yellow mosaic India virus (MYMIV) on urdbean in northwestern tarai region of India during *kharif* season 2012 and 2013 and reported that it ranged from 1.3-100% and 0.4%-100%, respectively.

Yadav et al. (2016) studied the seasonal abundance of whitefly on cluster bean. They observed first incidence of whitefly (2.56 whiteflies/3

leaves) in the 1st week of September (36th SW) and reached its peak (13.6 whiteflies/3 leaves) in the 4th week of September (39th SW). During this period maximum and minimum temperature, RH and rainfall were 33.30^{0}C, 25.12^{0}C, 78.00% and 69.00 mm, respectively. The pest remained available upto 4th week of October (43rd SW). Maximum and minimum temperature and rainfall had significant positive while RH had significant negative impact on whitefly population.

Kataria et al. (2017) conducted studies of population dynamics of whitefly on cotton for four consecutive years (2013-2016). They reported that the peak population of the pest was observed in the last fortnight of September during 2013 and 2014, while, during 2015 and 2016 it was in the first fortnight of August and September, respectively. Correlation studies revealed that it was not consistent over the years. However, during 2015 and 2016, minimum temperature and evening RH exhibited significant positive influence on whitefly population.

Singh et al. (2017) conducted field experiment during *kharif* on population dynamics of whitefly (*B. tabaci*) on urdbean. The first appearance of whitefly was observed during 34th SW and attained its peak population in the 37th SW. During this period the maximum and minimum temperature, RH and rainfall were 24.80^{0}C, 34.10^{0}C, 74.50% and 42.00 mm, respectively. Maximum and minimum temperature and rainfall showed positive while RH exhibited negative correlation with whitefly population, but statistically found to be non-significant.

Subba et al. (2017) reported that peak population of whitefly (*B. tabaci*) on tomato was observed during 11th SW (*i.e.* 2nd week to 3rd week of March). Morning and evening RH had significant negative impact on whitefly population. Whereas, maximum and minimum temperature and rainfall had exhibited negative correlation with whitefly population, but statistically found to be non-significant.

Sree et al. (2018) reported that the incidence of YVMV on okra transmitted by *B. tabaci* initiated during March and reached maximum during May. Maximum and minimum temperature had significant positive while morning RH had significant negative correlation with incidence of YVMV.

2.2 To study the presence of MYMIV in whitefly and soybean plant through molecular technique

The literature available on this aspect is scanty. Moreover there is no information available in the literature on PCR based detection of the virus both in vector and host plant throughout the cropping season.

Basu and Giri (1992) reported that the geminiviruses is of bipartite nature which have twinned icosahedral genomic components *viz.* DNA-A and DNA-B. The DNA-A contains the information required for replication and encapsidation of viral DNA, whereas DNA-B codes for movement protein which is responsible for the systemic spread and subsequent symptom development in the host plants. They further emphasized that the major host plant factors which influence plant susceptibility to viral infection include inherent genetic traits and plant age at the time of inoculation.

Hussain et al. (2004) characterized the MYMD with bright YMD symptoms on the leaves of infected plants of mungbean. They analyzed samples of infected mungbean plants with yellow mosaic symptoms collected from ten distinct locations of the North Western Frontier province and Punjab province of Pakistan to identify the begomovirus associated with the disease. The primer pairs FLDNAAF (TGTGGGATCCATTGTTGAACGACTTTCCC) and FLDNAAR (CAATGGATCCCACATTGTTAGTGGGTTCAG) were designed to amplify full-length DNA A of MYMIV through PCR studies. They revealed that the strategy for the detection of viral genomic components was based on the assumption that the begomovirus associated with the disease is related to MYMIV.

Malathi et al. (2005) isolated MYMIV from the infected cowpea plants which expressed golden mosaic symptoms and confirmed that it is being transmitted by whitefly. They further reported that the severity of the disease and infectivity rate depends on the genotype of the host plants.

Qazi et al. (2006) screened mothbean varieties under field conditions which exhibited severe YMD along with leaf curling on some varieties. Based on symptoms, the involvement of MYMIV was suspected and confirmed the identity of virus with specific primers for the DNA B-encoded nuclear shuttle

protein gene of MYMIV were used in PCR. They confirmed the association of MYMIV with YMD of mothbean and was the first report of MYMIV infecting mothbean in Pakistan.

Naimuddin and Akram (2010) reported golden mosaic disease of cowpea in India, is known to be caused by MYMIV. A severe YMD of cowpea in and around Kanpur was prevalent in *kharif* 2009. The primer pairs were designed to find a fragment of DNA containing coat protein gene of four begomoviruses *viz.,* Mungbean yellow mosaic India virus (MYMIV), Mungbean yellow mosaic virus (MYMV), Horsegram yellow mosaic virus (HgYMV), Dolichos yellow mosaic virus (DoYMV), known to infect various leguminous crops in India were used to detect virus (es) associated with golden mosaic disease of cowpea through PCR. They revealed that on the basis of nucleotide and deduced amino acids sequences of coat protein gene of MYMIV-(CpKn) had 95-99% and 96-100% similarity with other isolates of MYMIV and mixed infection of MYMIV and DoYMV in naturally infected cowpea.

Kamaal et al. (2011) noticed yellow mosaic of *Vigna mungo* var. *silvestris* as wild relative of blackgram (*V. mungo*) at the Indian Institute of Pulses Research (IIPR), Kanpur, India during 2008-2010, with an incidence of 100 per cent. The observed symptoms, consisting of veinal yellowing and scattered bright yellow spots, were suggestive of infection with a begomovirus. To characterize the virus, several sets of primer pairs were designed to amplify the targeted DNA fragments of the causal virus through PCR techniques. The sequence data revealed that the coat protein (AV1) gene of the begomovirus under study, infecting *V. mungo* var. *silvestris* is to be considered a strain of MYMIV- Visakhapatnam and was designated as MYMIV-VSKN. This was the first report of the molecular characterization of MYMIV infecting *V. mungo* var. *silvestris*.

Naimuddin et al. (2011) first reported natural infection of MYMIV in two wild species of *Vigna i.e. V. hainiana* and *V. trilobata*. During the rainy season 2010, *V. hainiana and V. trilobata grown* at IIPR, Kanpur, India, showed symptoms like yellowing of inter-veinal tissue and bright yellow spots in the leaves. Whiteflies (*B. tabaci*) were also noticed feeding on these plants. Type

of symptoms and presence of whitefly led to suspect the involvement of a begomovirus. They detected begomovirus by PCR using primer pairs specific to MYMIV and MYMV that commonly infect cultivated species of *Vigna* (*V. mungo and V. radiata*) in different parts of India.

Islam et al. (2012) reported identification of YMD and characterization of MYMIV coat protein (CP) gene from mungbean. Samples which exhibited yellow mosaic symptoms were identified through PCR, using conserved region primers designed after alignment of the available CP sequences in National Center for Biotechnology Information data base. Sequence analysis of the PCR amplified samples showed 97% sequence similarities with the coat protein gene of MYMIV-Bangladesh strain and was designated as MYMIV-BD. This was the first report of the molecular identification of MYMIV in Bangladesh which cause major yield loss of mungbean.

Shahid et al. (2012) first identified MYMIV through molecular studies on kidney bean which showed severe mosaic, yellowing and leaf curl symptoms and the maximum YMD incidence recorded was 70-80%.

Singh et al. (2013) confirmed the presence of YMD on soybean (cv. JS 335, JS 95-60 and NRC 37) through PCR studies which was caused by MYMIV, belonging to the genus Begomovirus. They revealed that YMD is a major constraint in soybean production in South-East Asia.

Jeevan et al. (2014) reported that YMV in French bean, which is transmitted by whitefly is a serious disease in southern India. The typical disease symptoms initially appear in the form of golden yellow colour on leaves and later become partially or completely yellow.

Naimuddin et al. (2014) confirmed the YMD through PCR studies in weed *Ageratum conyzoides* and revealed that YMD caused by MYMIV is one of the important biotic constraints to mungbean and urdbean production. They further revealed that *A. conyzoides* act as an alternate host of MYMIV. Of the forty plants of *A. conyzoide*s which showed yellow vein symptoms were subjected to the PCR based detection of viruses which caused YMD in pulse crops. About 52.5% samples were found positive with primers specific to MYMIV. The virus was successfully transmitted by whiteflies from weed to

cultivated hosts (mungbean and urdbean) and induced typical yellow mosaic symptoms.

Ramesh et al. (2016) conducted studies on nucleotide diversity and DNA polymorphism by geographical confinement of species of YMV infecting soybean. The YMD infected soybean samples were collected from Northern, Central, Southern and Western regions of India. The PCR assay revealed that MYMIV was detected from the samples of Northern and Central regions while, MYMV from Southern and Western regions of India.

Marabi et al. (2017) identified four weed species (*viz.*, *Ageratum conizoides, Vigna trilobata, Corchorus olitorius* and *Alternanthera sessilis*) through molecular studies by using specific MYMIV molecular markers (DNA-A and DNA-B) and confirmed that these weeds act as alternate hosts during the off season of legume crops (*viz. Cajanus cajan, Glycine max, Phaseolus vulgaris, Vigna mungo*, *Vigna radiata* and *Vigna unguiculata*), being transmitted by the whitefly and are responsible for carryover of the virus.

Nair et al. (2017) collected leaf samples of mungbean and other legume plants and weeds which showed virus-like symptoms from mungbean growing regions in India during 2012-2014. DNA was extracted by using the DNeasy Plant Mini Kit and amplified with specific and universal primers through PCR techniques. They reported that MYMV-Urdbean was dominant in Northern Indian states (Punjab and Delhi), while MYMIV in Eastern India (Jharkhand), whereas, MYMV-Vigna was found in Southern Indian states (Tamil Nadu, Karnataka and Telengana).

Ramesh et al. (2017) identified through PCR based diagnosis that the yellow mosaic viruses (Genus: Begomovirus: Geminiviridae) are serious pathogens of grain legumes and leguminous weeds, infecting soybean and the associated weed species *Vigna trilobata* in soybean.

2.3 To study the virus (MYMIV)-vector (*B. tabaci*) relationship in soybean in insect proof net house

Nariani (1960) conducted transmission study of yellow mosaic through whitefly by giving an acquisition access period (AAP) of 24 h on YMD infected plants and inoculation access period (IAP) of 24 h on eleven individual healthy

seedlings of soybean. After inoculation, plants were kept under observation for 1 ½ months. They reported that the yellow mosaic symptoms appeared on 50% plants, after 18-19 days of inoculation.

Mansour and Al-Musa (1992) studied the vector (*B. tabaci*)-virus (tomato yellow leaf curl virus-TYLCV) relationship and found that a single whitefly when given a minimum AAP of 60 min and IAP of 30 min was efficiently able to transmit the virus in the tomato plant. Further, the virus retention period in the vector was 11 days.

Mehta et al. (1994) conducted transmission study of TYLCV with the vector, *B. tabaci* on tomato. They observed that the transmission of TYLCV was achieved with single adult whitefly/ plant, but the efficiency of transmission increased fourfold when the number of adult whiteflies increased to 5 per plant. They further revealed that minimum AAP and IAP recorded was 15 minutes, while maximum was 24 and 12 h, respectively. In the serial transfer studies they observed that when 24 h of AAP was given, the vector failed to transmit the virus and this condition prevailed regardless of the length of AAP.

Ghanim et al. (2001) reported that ten whiteflies (*B. tabaci*) were able to transmit 50% TYLCV when they were given 8 h of AAP and 1 h of IAP. While, maximum transmission efficiency (100%) was recorded when they were given 48 and 24 h of AAP and IAP, respectively.

Aidawati et al. (2002) observed that a single whitefly was able to transmit the Tobacco leaf curl virus (ToLCV) and the efficiency of transmission was maximum (100%), when the number of adult whiteflies increased upto 20 per plant. They further reported that at three different durations of AAP *viz.* 1, 12 and 24 h, followed by IAP of 48 h, the vector transmitted 20, 90 and 100% disease, respectively.

Biswas (2002) conducted an inoculation study of mungbean yellow mosaic geminivirus through whitefly allowing 24 h each of AAP and IAP. Total 8-10 viruliferous adult whiteflies/plant were used at two leaf stage of soybean seedling (3 days after germination). He reported that the degree of disease reaction varied from soybean variety to variety and most of the varieties

recorded more than 60% infection, while highest was 88.8%. Resistant variety took longer time, about 16-29 days after IAP to produce symptoms, whereas susceptible variety took shorter period of 8-18 days.

Czosnek et al. (2002) conducted whitefly-mediated transmission of TYLCV on tomato plants where disease symptoms have indicated that the minimum AAP and IAP were 15 and 30 minutes, respectively.

Mann and Singh (2004a) studied the relationship of Cotton Leaf Curl Virus (CLCuV) with its vector, *B. tabaci* on cotton. Non-viruliferous whiteflies were allowed an AAP of 8 h on the virus source. The viruliferous whiteflies in different numbers *i.e.* 1, 5, 10, 15, 20 and 25 per plant were allowed an IAP of 2 h on the test plants. A single viruliferous whitefly per plant gave 20% virus transmission. Whereas the virus transmission with 5, 10, 15, 20 and 25 whiteflies/ plant was 80, 87, 85, 90 and 88%, respectively.

Mann and Singh (2004b) studied the relationship of CLCuV with its vector, *B. tabaci* on cotton and revealed that whitefly required an acquisition and inoculation threshold period of 20 and 10 min, respectively and a latent period of 8 h for successful transmission of the virus. They concluded that the virus transmission increased with increase in acquisition and inoculation access periods.

Khan and Ahmad (2005) studied the relationship between vector (*B. tabaci*) and CLCuV on cotton. They revealed that the acquisition and inoculation access threshold periods for CLCuV transmission by *B. tabaci* were 4 and 1 h, respectively. A minimum of two whiteflies could induce CLCuV symptoms. They further emphasized that maximum efficiency of disease transmission was recorded when *B. tabaci* were allowed for 24 h each of AAP and IAP.

Rajnimala et al. (2005) reported that a minimum of 5 whiteflies are required to transmit the Bitter gourd YMV virus. However, 100% transmission of the virus was recorded when 45 whiteflies were released per plant for 12 h each of AAP and IAP. They inferred that transmission of virus increased with increase in both AAP and IAP.

Usharani et al. (2005) reported that with 24 h each of AAP and IAP, the symptoms of MYMIV was expressed after 8-13 days of inoculation through whitefly in seven days old healthy seedlings of French bean, urdbean, mungbean and cowpea whereas, it was17 days in soybean.

Lapidot (2007) studied virus (TYLCV)-vector (*B. tabaci*) relationship and revealed that when 30-40 whiteflies/ plant were given 48 h each of AAP and IAP in tomato plants, the disease incidence recorded was 100%.

Nagata et al. (2007) conducted an experiment on transmission of tomato mottle leaf curl virus on tomato with three, five and ten whiteflies/plant by allowing them 48 h each of AAP and IAP. They reported that all the plants (6 plants/treatment) inoculated with ten and three viruliferous whiteflies were infected within one month. However, the results were not consistent, as only one plant out of six remained uninfected when five viruliferous whiteflies were used.

Biswas et al. (2008) carried out an inoculation study of MYMIV through whitefly, *B. tabaci* on fourteen genotypes of pigeonpea. Non-viruliferous adult whitefly were given AAP of 24 h on virus infected source plants (urdbean) and then 8-10 viruliferous whiteflies/plant were used on healthy test plants at two leaf stage for IAP of 24 h. Inoculated pigeonpea plants produced disease symptoms within 9-27 days after inoculation, however, the time taken to produce symptoms in resistant and susceptible genotypes did not vary much.

Biswas et al. (2009) collected leaf samples of urdbean which showed YMD like symptoms and used them as source of inoculum for insect transmission studies. Adult whiteflies were given AAP of 24 h on infected source plants and then 8-10 viruliferous whiteflies/plant were released on healthy plants at two-leaf stage (3 days after germination) for IAP of 24 h. After 10-15 days of inoculation typical yellow mosaic symptoms were expressed in healthy seedlings. Transmission efficiency varied from 40-60%, and the YMD infected plants were confirmed as MYMIV through PCR.

Yadav et al. (2009) studied MYMIV transmission through whitefly (*B. tabaci*) on soybean (cv. JS 335) and revealed that 23% disease infection was scored when a single whitefly/plant was given 24 h each of AAP and IAP.

Initially yellow mosaic symptoms started appearing within 18–20 days on the fifth tri-leaf and maximum infected plants (100%) were recorded within 30 days after inoculation.

Shivakumar (2010) conducted transmission studies of Zinnia leaf curl virus (ZLCV) through whitefly, *B. tabaci* on Zinnia (*Zinnia elegans* L.). Five non-viruliferous adult whiteflies were allowed with 24 h each of AAP and IAP and recorded hundred per cent transmission of ZLCV disease on Zinnia.

Kamaal et al. (2011) collected whiteflies (*B. tabaci*) feeding on yellow mosaic diseased *V. mungo* var. *silvestris* plants from fields at Kanpur. The viruliferous whiteflies were released (40-50 whiteflies/5 plants) on 10-15 days old healthy *V. mungo* var. *silvestris* plants grown in a net house with an IAP of 48 h. Symptoms of yellow mosaic started appearing 10 days after inoculation. They further observed that after thirty days of inoculation, 7 plants out of 15 inoculated plants (46.7%), developed yellow mosaic symptoms similar to those seen in the field, which indicated that the disease causaing virus was transmitted by the whiteflies. They also confirmed the begomovirus infecting *V. mungo* var. *silvestris* as a strain of MYMIV.

Senanayake et al. (2012) studied the relationship of chilli leaf curl virus in chilli with its vector, *B. tabaci* by allowing 24 h each of AAP and IAP to determine the threshold level of whiteflies, minimum AAP and IAP and serial transfer of virus. They revealed that a single whitefly and eight whiteflies/ plant registered 66.6 and 100% transmission within 13-18 and 7-10 days after inoculation, respectively. The minimum AAP and IAP determined were 3 h and 1 h, respectively with a vector population of 10-15 whiteflies/plant. In the serial transfer studies, the maximum retention period was 5 days and the mortality of the vector started from 6^{th} day onwards.

Srinivasan et al. (2012) carried out TYLCV transmission studies on 30 days old tomato plants by allowing 72 h each of AAP and IAP to female adult whiteflies (*B. tabaci*) and released twenty viruliferous whiteflies/ plant. They observed that the disease incidence was 55±5.0 and 85±5.0% in resistant and susceptible varieties, respectively.

Gazala et al. (2013) conducted MYMIV transmission study through whitefly in soybean (cv. JS 335). They observed that with 18 h of AAP and 24 h of IAP, the MYMIV symptoms developed after 20 days of inoculation was in the form of mild scattered yellow specks in soybean plants.

Bag et al. (2014) studied transmission of MYMV through *B. tabaci* on urdbean by allowing ten adult whiteflies/ plant with 12 h each of AAP and IAP. They reported that after 7-10 days of inoculation, the disease incidence was 81%.

Govindan et al. (2014) observed that when ten adult whiteflies were given an AAP of 24 and 48 h followed by an IAP of 24 h, were able to transmit MYMIV disease in mungbean plant, which ranged from 50.00-70.50% and 70.00-85.50%, respectively. They inferred that longer AAP resulted in higher transmission of disease.

Njoroge et al. (2017) carried out experiments on virus (cassava mosaic disease)-vector (*B. tabaci*) relationship on cassava plants. They reported that a minimum period of 6 h was required for whitefly to feed and transmit the viral disease. Further, with increase in the vector density *viz.* 5, 10 and 20 whiteflies/ plant, there was an increase in the disease incidence *viz.* 8±14, 17±11 and 33±33%, respectively.

Haq et al. (2018) studied the transmission of TYLCV through *B. tabaci* on tomato and revealed that the vector when given 24 h each of AAP and IAP and released @ single whitefly/ plant, there were 25% disease transmission and it attained 100% at 5 whiteflies/ plant. The minimum AAP and IAP recorded was 30 and 20 minutes, respectively. The virus persisted in its vector upto 10 days after serial transfer which indicated that the virus showed persistent type of transmission.

MATERIAL AND METHODS

This chapter includes details of the material used and methodology followed during the course of present investigation entitled "Studies on whitefly, *Bemisia tabaci* Genn., vector of mungbean yellow mosaic India virus (MYMIV) with special reference to seasonal fluctuation and virus-vector relationship in soybean". According to the objectives the studies were divided into three sections as detailed below:

1. To study the seasonal incidence of whitefly and yellow mosaic disease in soybean crop.
2. To study the presence of MYMIV in whitefly and soybean plant through molecular technique.
3. The virus (MYMIV)-vector (*B. tabaci*) relationship in soybean in insect proof net house.

3.1 Location

The experiment was conducted on the Entomology Experimental Farm, Adhartal Tank area, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh during three consecutive seasons (*rabi*, summer and *kharif*) of 2014-15, 2015-16 and 2016-17. Studies on virus-vector relationship were carried out in insect proof net house during *kharif* 2015-16 and 2016-17.

3.2 Geographical location and climate

Jabalpur is situated at 23.09° N latitude and 79.58° E longitude at an altitude of 411.78 m above the mean sea level. Jabalpur comes under the agro-climatic zone-IV Kymore Plateau and Satpura Hills and lies in rice-wheat crop zone of the state. It falls under subtropical climatic conditions, which is characterized by the features of hot dry summers and cool dry winters. The rainfall is often most erratic and ill-distributed along with an occasional long dry spells or frequent heavy rainy days during the rainy season. The mean annual rainfall is nearly 1423 mm, which is received mostly between mid-June to mid-September (www.mp.gov.in/agro-climatic-zones).

The maximum and minimum temperature ranges between 24°C to 45°C and 2°C to 32°C, respectively within a year. In some of the years, maximum temperature reaches as high as 45°C in the month of May or June. The relative humidity varies from season to season and ranges between 80 to 90% during rainy season, 60 to 70% during winter season and 30 to 40% during summer season (www.mp.gov.in/agro-climatic-zones).

The weather data during the period of experiment *i.e.* 2014, 2015 and 2016 are presented in Appendix I and II.

3.3.1 To study the seasonal incidence of whitefly and yellow mosaic disease in soybean crop.

Experimental details:

1. Crop : Soybean
2. Variety : JS 335
3. Season : *Rabi*, summer and *Kharif*
4. Plot size : 1 Acre area
5. Spacing (Row × Plant) : 45 cm x15 cm
6. Fertilizer dose : N: P: K @ 40:60:40
7. Sowing dates :

Season	Date of sowing in different year		
	2014-15	**2015-16**	**2016-17**
Rabi	13-11-2014	03-12-2015	-
Summer	-	21-03-2015	22-02-2016
Kharif	-	07-07-2015	24-06-2016

8. Plant protection : Unprotected

Methods of observation:

Whitefly

The observations on adult whitefly population was recorded twice in a standard week (SW) on randomly selected 10 plants with the help of cage (Plate 1). Cage was prepared with transparent fiber cylinder of different height and diameter 20x15, 25x20, 35x30 cm, respectively. The inner walls of the cylinders were coated with black paint to induce darkness and one end of cylinder was left open while the other end was closed with a transparent glass and was fixed in such a manner that no space was left for escape of the adult whitefly from inside the cage. To record the number of adult whitefly population the cage was placed on an individual plant carefully without disturbing it. The adult whitefly congregated on the inner surface of the glass pane due to its phototactic behavior which enabled to count them easily.

In the early stage of the crop growth, narrow diameter cages were used while in the later stages, cages having broader diameter with more height having sufficient space to cover an individual plant were used for recording the observations. The observations of whitefly was initiated immediately after germination and was continued till the availability of the insect or maturity of the crop, whichever was earlier. Daily meteorological data *viz.,* maximum and minimum temperature, morning and evening relative humidity, wind speed, sunshine hours, morning and evening vapour pressure, evaporation and rainfall were obtained from JNKVV meteorological observatory.

Yellow mosaic disease

Yellow mosaic disease infection was recorded on 20 tagged plants at weekly interval following the rating system (0-9) as proposed by Wheeler (1969) (Table 1). The yellow mosaic infected plants (YMD) were identified visually. Initially it appeared as yellow patches on soybean leaves and later coalesced to form a larger patch that developed into yellow or necrotic mottle, eventually the entire leaf turned yellow. The green areas appear as dark green islands interspersed in yellow chlorotic areas, and the leaf blade appears wavy (Islam and Faruq, 2009). Soybean leaves which showed yellow mosaic symptoms were collected and analyzed for MungbeanYellow Mosaic

India Virus (MYMIV) through PCR techniques following the protocols of O'Neill et al. (1992) and Islam et al. (2012).

The incidence of yellow mosaic virus disease severity was determined by calculating the percent disease index (PDI) as follows:

$$PDI\ (\%) = \frac{\text{Sum of individual disease rating}}{\text{Total number of leaves observed}} \times \frac{100}{\text{Maximum disease grade}}$$

Table 1: Disease scale rating of soybean yellow mosaic disease

Rating	Description
0	No symptoms on plant
1	Yellow mottle or necrotic mottle - upto 1% leaves
3	Yellow mottle or necrotic mottle in traces - 1.1 to 10% leaves
5	Necrotic mottle/mild mottle /mild symptoms - 10.1 to 25% leaves (no reduction in plant growth)
7	Yellow mottle symptoms not covering the whole leaf lamina - 25.1 to 50% leaves (reduction in leaf and plant growth)
9	Yellow mottle symptoms on more than 50% leaves (severe reduction in leaf and plant growth as well as pod formation and death of plant)

3.3.1.1 Statistical analysis

(a) i. Correlation and regression

Correlation and regression of the abiotic factors with whitefly population and YMD were computed by using the formula as suggested by Snedecor and Cochran (1967).

$$\text{Correlation 'r'} = \frac{\sum xy - \frac{\sum x . \sum y}{n}}{\sqrt{\left\{\sum x^2 - \frac{(\sum x)^2}{n}\right\}\left\{\sum y^2 - \frac{(\sum y)^2}{n}\right\}}}$$

Where,

r = Correlation coefficient

$\sum xy$ = Sum of product of both variables x and y

$\sum x$ = Sum of variable x

$\sum y$ = Sum of variable y

$\sum x^2$ = Sum of square of variable x

$\sum y^2$ = Sum of square of variable y

n = Number of observations

(a) ii. Test of significance of correlation coefficient 'r'

For testing the significance of the correlations, they were compared with the table value at (n-2) degree of freedom at 5% and 1% significant level.

$$t = \frac{r}{\sqrt{1- r^2}} \sqrt{n-2}$$

Where,

t = Calculated ' t ' value

r = Correlation coefficient

n = Number of observations

(a) iii. Regression

$$\hat{Y} = a + bx (R^2)$$

Where,

a = Intercept

b = Regression coefficient

R^2 = Coefficient of determination

(b) Multiple regression

Multiple regression analysis of the independent variables *viz.* abiotic factors and crop age on dependent variable *i.e.* whitefly population was computed. Subsequently, multiple regression of independent variables (x) *viz.* abiotic factors, vector population and crop age on independent variable (Y) (YMD infection) was computed in three phases *viz.* x and Y of same weeks, X of preceding one and two weeks of Y.

(c) Paired 't' test

Paired test was applied between whitefly population of first and second year on *kharif* planted soybean crop and was computed as suggested by Snedecor and Cocharan (1967):

$$\text{Paired 't' test} = \frac{\bar{d}}{s\sqrt{n}}$$

Where,

$$\bar{d} = \sum_{i=1}^{n} \frac{di}{n}$$

$$S^2 = \frac{1}{n-1}(\sum di^2)-(\sum di)^2/n$$

Where,

di = Difference between the sample means

$\bar{d}$ = Mean of the difference

S = Standard deviation

n = Number of observations

$\sum$= Summation

(d) Unpaired 't' test

Unpaired 't' test was applied between the whitefly population on soybean crops recorded in different years and seasons (*i.e. rabi* and summer). The methodology proposed by Snedecor and Cocharan (1967) was adopted:

$$\text{Unpaired 't' test} = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s^2\,(1/n_1+1/n_2)}}$$

Where,

$$S^2 = \frac{\sum(x_i-\bar{x}_1)^2 + \sum(x_j-\bar{x}_2)^2}{n_1 + n_2 - 2}$$

Where,

X_1 = Mean of the first set of unpaired data

X_2 = Mean of the second set of unpaired data

S^2 = Pooled standard deviation of the unpaired data

n_1 = Sample size of the first set of unpaired data

n_2 = Sample size of the second set of unpaired data

$\sum$ = Summation

(e) Path coefficient analysis

The direct and indirect contribution of abiotic factors on whitefly population were calculated through path coefficient analysis as suggested by Wright (1921) and elaborated by Dewey and Lu (1959).

The following set of simultaneous equations were formed and solved for estimating direct and indirect effects.

$$\left|\begin{array}{l} r_1Y = r_{11}P_1Y + r_{12}P_2Y + r_{13}P_3Y + \ldots\ldots\ldots\ldots + r_{1k}P_kY \\ r_2Y = r_{21}P_1Y + r_{22}P_2Y + r_{23}P_3Y + \ldots\ldots\ldots\ldots + r_{2k}P_kY \\ r_kY = r_{k1}P_1Y + r_{k2}P_2Y + r_{k3}P_3Y + \ldots\ldots\ldots + P_kY \end{array}\right|$$

Where,

r_1Y to r_kY = Coefficients of correlation between causal factors 1 to 'k' and independent character Y

P_1Y to P_kY = Direct effects of characters 1 to 'k' on character Y

r_{12} to $r_{k-1,\,1}$ = Coefficient of correlation among causal factors

The above equations were written in a matrix form as under

$$\begin{array}{ccccc} A & & C & & B \\ \begin{bmatrix} & \\ & \\ & \\ \vdots & \\ & \\ & \end{bmatrix} & & \begin{matrix} \cdots \\ \cdots \\ \vdots \quad \vdots \quad \vdots \quad \vdots \\ \cdots \end{matrix} & & \begin{bmatrix} & \\ & \\ & \\ \vdots & \\ & \\ & \end{bmatrix} \end{array}$$

Then, $B = C^{-1}$.

Where,

$$C^{-} = \begin{bmatrix} & & \cdots & \\ & & \cdots & \\ \vdots & \vdots & \vdots & \vdots \\ & & \cdots & \end{bmatrix}$$

Then direct effects were calculated as follows --

$$P_1Y = \sum_{i=1}$$

$$P_2Y = \sum_{i=1}$$

$$P_kY = \sum_{i=1}$$

Residual effect (R) was obtained as per the formula given below –

$$R = \sqrt{1 - \sum}$$

Where,

d_i = Direct effect of the i^{th} character

r_{ij} = Correlation coefficient of the i^{th} character with j^{th} character

3.3.2 To study the presence of MYMIV in whitefly and soybean plant through molecular technique.

For conducting studies on presence of MYMIV in vector whitefly and host soybean plant through molecular technique, the experimental details were as follows:

3.3.2.1 Detection of MYMIV both in vector and host plant through PCR

3.3.2.1.i Materials

In order to establish relationship between viruliferous whiteflies and disease expansion in the host plant, whitefly and soybean leaf samples were collected from 7 days old crop, which was carried out at weekly interval from

the experimental field of objective 1. Collection of the vector samples continued upto their availability on the crop while leaves samples were collected until the crop attained maximum YMD infection.

3.3.2.1.ii Whitefly samples

Twenty adult whiteflies per sample were collected from soybean crop with the help of aspirator which were kept in 100 percent acetone solution in glass vials and stored in normal freeze condition at 3^0C for further use (Singh et al. 2015).

3.3.2.1.iii Plant materials

As per the methodology proposed by Singh et al. (2015), about 100 mg of soybean leaf samples were collected from 20 tagged plants which were kept in sterilized zip plastic packets and temporarily kept in ice box in the field which were transferred in deep freezer at -20^0C in the lab for the molecular studies.

.3.3.2.1.iv Chemicals

The chemicals used in the present study were either of molecular grade or analytical grade. List of chemicals used are given in the Appendix-III and also cited at appropriate places.

3.3.2.1.v Glass and plastic wares

All the glasswares used in the study were of Borosil, India Ltd. They were thoroughly washed and sterilized as per standard procedures. Plastic wares *viz.,* micro-tips, micro centrifuge tubes, PCR strips, falcon tubes *etc.*, were of Tarsons, India.

3.3.2.1.vi Buffers and solutions

Composition of buffers and solutions used in the present study are presented in the Appendix -IV.

3.3.2.1.vii Molecular markers

3.3.2.1.vii.a Whitefly specific markers

For confirmation of whitefly mitochondria, specific molecular marker COI was used and its sequence presented in Table 2.

3.3.2.1.vii.b Legume specific markers

For confirmation of soybean 18s r-RNA, specific primers *viz.,* NS1 and NS4 which were developed from conserved region, were used and their sequences are mentioned in Table 2.

3.3.2.1.vii.c MYMIV specific markers

For molecular detection of virus in whitefly and diseased plants, MYMIV specific primers *viz.*, DNA-A (Coat protein) and DNA-B were used in PCR-amplification as proposed by Islam et al. (2012). Information on sequence of these primers are mentioned in Table 2.

Table 2: Sequence of molecular markers

Molecular Markers		Sequence
Legume specific	NS	NS1 : GTAGTCATATGCTTGTCTC
		NS4 : CTTCCGTCAATTCCTTTAAG
Whitefly specific	COI	Forward: GGTTYTTTGGTCATCCRGARGTTTATG
		Reverse: CTCTTTAAAACTRTGMYTAAGRRCYGG
MYMIV specific	CP (DNA-A)	Forward: ACACGGATCCGTTGCATACACAGGATTTG
		Reverse: ACACGAGCTCCTCTACCCCGATATCGAATG
	DNA-B	Forward: AGCCTATGACACCGTCAAGAGGA
		Reverse: CGCCGGGACAACGGCATAT

3.3.2.1.viii Molecular analysis

Molecular analysis was carried out as per the methodology proposed by Singh et al. (2015)

1. Isolation of genomic DNA
2. DNA quantification
3. DNA amplification using molecular markers
4. Agarose gel electrophoresis of PCR products.
5. Analysis of marker data.

3.3.2.1.ix DNA isolation

3.3.2.1.ix.a DNA isolation from whitefly

DNA was isolated from individual whitefly by the following procedure as suggested by Singh et al. (2015):

Procedure:

1. 30µl of STE buffer (100mM NaCl, 1mM EDTA - pH 8.0, 10mM Tris-HCl -pH 8.0) was taken in an eppendorf microcentrifuge tube.
2. Single whitefly was introduced in an eppendorf microcentrifuge tube using fine pointed paint brush (Zero number brush - Camel).
3. Whitefly was crushed using micro pestle to make homogenate solution.
4. 2 µl of proteinase-K (10mg/1ml) was added to the homogenate and mixed thoroughly.
5. Microcentrifuge tubes containing homogenates were incubated at 55^0C for 30 min in heating block.
6. They were then transferred to another heating block and incubated at 90^0C for 5 min.
7. Microcentrifuge tubes were then centrifuged slightly so that the liquid could settle at bottom of tubes.
8. DNA solution thus obtained was stored in refrigerator for further use.

3.3.2.1.ix.b Plant DNA isolation

DNA from all the collected soybean leaf samples were isolated by using DNeasy Plant Mini Kit (Qiagen) and were stored in refrigerator for further use.

3.3.2.1.ix.c DNA quantification

The methodology of DNA quantification of whitefly and leaf was carried as suggested by Singh et al. (2015) by using spectrophotometer.

Procedure:

1. The spectrophotometer in the photometric mode was adjusted with wavelengths set at 260 nm and 280 nm.

2. The spectrophotometer was adjusted with $T_{10}E_1$ buffer as blank.
3. 5µl of DNA sample was taken with a cut tip and added to 995µl of TE in a 1ml cuvette. This was mixed well by gentle inversion and the OD readings were noted.
4. The same procedure was repeated with another lot of the same sample.
5. The $OD_{260:280}$ ratios were calculated which represents the purity of DNA.
6. The amount of DNA in the sample was calculated using the formula:

    1-OD = 50µg DNA (taking the dilution factor into consideration)

    DNA (µg/ml) = OD_{260}× Dilution factor × 50

Purity of the DNA was given by the ratio $OD_{260/280}$. It should be ~1.8 for pure DNA and will fluctuate in the presence of contaminants like RNA (≥1.8) or proteins (≤1.8).

3.3.2.1.ix.d Normalization of DNA concentration

The methodology for normalization of DNA concentration was followed as proposed by Singh et al. (2015). It was carried out to equalize the concentration of all the samples, to avoid erroneous analyses due to differences in the brightness of the bands obtained after electrophoresing the PCR products.

Normalization was carried out by diluting the DNA samples with sterile distilled water to their required dilution factor which depends upon the initial concentration of DNA sample (obtained from spectrophotometric readings) and also the type of analysis done (*i.e.* markers used). After normalization of the samples the concentration of DNA was 50ng/µl.

3.3.2.1.ix.e Polymerase chain reaction (PCR)

As suggested by Mullis et al. (1986), PCR was used to selectively amplify *in vitro* a specific segment of the DNA to a billion fold. The most essential requirement of PCR is the availability of a pair of short (typically 20-25 nucleotides) primers having sequence complementary to either end of the target DNA segment (called template DNA). Reaction mixture was used for SSR PCR following the protocols of O'Neill et al. (1992). 50ng DNA (1µl) was

used per PCR to which 24µl master mixture (PCR reaction mixture) was added. Thus total quantity of 25µl was maintained in each tube. The PCR mixture was centrifuged at 1000 rpm for 1 min and loaded in a 96 wells thermal cycler of PCR (Bio-Rad). The program comprised of initial denaturation at 94^0C for 1 min which was further followed by 30 cycles at 94^0C for 20 sec, 56^0C for 20 sec and 72^0C for 1 min. Final extension was carried out at 72^0C for 3 min and stored at 15^0C for further use (Table 3). The amplified products were used for electrophoresis.

PCR reaction was carried out in small PCR tubes with genomic DNA as template and the primer(s) that amplifies DNA sequence were used. The reaction was carried out in 25 µl volumes, which contained 1.0µl (25ng) of soybean genomic DNA, 1.0µl (2.5pmole) of forward and reverse primers each, 1.0µl (2.0mM) of dNTPs, 2.5µl of Taq buffer (10X), 1.6µl of $MgCl_2$ (25mM) and 1 units of Taq polymerase (Table 4).

Thermo cycling was carried out on a 96 well PCR system (Bio-Rad) in which 0.2 ml thin walled PCR tubes were placed and the DNA amplification program was initiated as mentioned in Table 3.

Table 3: PCR programme

Steps followed in Thermal cycler	**Temperature in ºC for one cycle**	**Time for one cycle**
Marker	DNA-A(CP)/DNA-B Specific	
Step 1	94ºC	1 min
Step 2	94ºC	20 sec
Step 3	56ºC	20 sec
Step 4	72ºC	1 min
Step 2 – Step 4 were repeated for 30 cycles		
Step 5	72ºC	3 min
Step 6	Maintained at 15ºC until ready to load onto gel	

Table 4: Components used in polymerase chain reaction

Components	Stock concentration	Quantity required for 1 reaction (μl)
Template DNA	50ng/μl	1.0
Sterile distilled water	-	15.9
PCR buffer	10X	2.5
$MgCl_2$	25mM	1.6
dNTP's	2.5mM	1.0
Forward Primer	2.5pmole	1.0
Reverse Primer	2.5pmole	1.0
Taq DNA Polymerase	1U/μl	1.0
Total volume		25

3.3.2.1.ix.f Separation of PCR amplified products on agarose gel

The amplified products were resolved on 1.0% agarose gel. The agarose gel was prepared by adding 1.0 gm of agarose to 100 ml 1X TAE buffer in a flask of 250ml capacity and boiled carefully till the agarose melted completely. After cooling the gel to 55-60 ^{0}C, the gel was poured in the tray containing the comb, avoiding formation of air bubbles. The solidified gel was transferred to horizontal electrophoresis apparatus and 1X TAE was added to cover the gel.

To the PCR product, 2μl of 6X loading dye was added and the whole mixture was loaded in the gel carefully. 100bp ladder was also loaded along with PCR products. The gel was run at a constant voltage of 100V for about 30 minutes (until the tracking dye migrated to the end of the gel).

3.3.2.1.ix.g Staining of agarose gel

The gel was transferred to plastic tank containing 25μl of DNA staining dye - ethidium bromide in 100 ml of distilled water and kept for staining for 30 minutes.

3.3.2.1.ix.h PCR product visualization

The gel was observed under gel documentation system and amplified products were visualized and positive bands were scored.

3.3 The virus (MYMIV)-vector (*B. tabaci*) relationship in soybean in insect proof net house

3.3.1 Experimental materials

Materials such as soybean seeds, wooden pegs, thread, cage, aspirator, measuring cylinder, weighing balance, magnifying lens, stop watch, card sheet paper, butter paper bags, rubber band, fine camel brush and earthen pots were used for conducting studies on virus-vector relationship.

3.3.2 Culturing of insect and virus source

Culturing of vector and virus sources was carried out in insect proof net house as per the methodology proposed by Aidawati et al. (2002). Healthy non-viruliferous colonies of whiteflies were maintained on healthy soybean plants which were used for MYMIV transmission studies. Simultaneously soybean plants which showed typical MYMIV symptoms were collected from the field, were confirmed by molecular studies through PCR technique and were maintained as virus source. Soybean cultivar JS-335 reported to be highly susceptible to YMD (www.jnkvv.org) was used as test plant for transmission studies. The plants were raised from healthy seeds in ten inch earthen pots filled with mixture of soil, sand and compost in 2:1:2 ratio (w/w), respectively and maintained in insect proof net house.

3.3.3 Virus-vector relationship

Studies on virus vector relationship were conducted as suggested by Czosnek et al. (2002). Non-viruliferous adult female whiteflies were reared on healthy soybean plant under insect proof net house. Seven days old adult female whiteflies were included in the studies which were given two hrs of starvation period before acquiring virus from MYMIV-infected plants (Cohen and Nitzany, 1966 and Ghanim et al. 2001).

3.3.3.1 Acquisition access period (AAP)

For determining the minimum period of AAP, non-viruliferous adult female whiteflies @ 10 per plant were exposed on infected plants for different durations *i.e.* 0.5, 1, 3, 6, 12 and 24 hrs for acquiring the virus which was replicated 10 times. Thereafter, the 10 viruliferous whiteflies per plant of each treatment were released on 7 days old healthy soybean seedlings (DOHSS) for 24 hrs for transmitting the virus *i.e.* inoculation access period (IAP). After 24 hrs of IAP, the whiteflies were withdrawn from the seedlings. The inoculated seedlings were allowed to grow under insect free condition which were monitored regularly to observe the development of yellow mosaic symptoms and accordingly the intensity of infection and duration required for symptom expression were recorded.

3.3.3.2 Inoculation access period (IAP)

In order to determine the minimum period of IAP, non-viruliferous adult female whiteflies were released @ 10 per plant on MYMIV-infected soybean plants for 24 hrs for acquiring the virus which was replicated 10 times *i.e.* AAP. Thereafter, the viruliferous whiteflies were transferred on 7DOHSS and allowed to inoculate the virus for different durations of IAP *viz.* 1, 3, 6, 12, 18 and 24 hrs. Henceforth, whiteflies were withdrawn and the inoculated seedlings were allowed to grow under insect free condition which were monitored regularly to observe the development of yellow mosaic symptoms and accordingly the intensity of infection and duration required for symptom expression were recorded.

3.3.3.3 Vector population

Studies on impact of vector population density on virus transmission was carried out with non-viruliferous adult female whiteflies which were released on MYMIV infected soybean plants for a period of 24 hrs AAP. Thereafter, a known number of viruliferous whitefly population *viz.,* 1, 3, 5, 10, 15 and 20 per plant were transferred on 7 DOHSS for 24 hrs of IAP. Subsequently, the whiteflies were withdrawn from the seedlings. The inoculated seedlings were allowed to grow under insect free condition which were monitored regularly to observe the development of yellow mosaic symptoms and accordingly the intensity of infection were recorded.

3.3.3.4 Retention period of virus in the vector

Studies on serial transmission of whitefly was conducted to determine the persistence period of the virus in its vector. For this purpose non-viruliferous adult female whiteflies were allowed a 24 hrs AAP on MYMIV source and the viruliferous insects were transferred serially @ single adult female whitefly/ plant at every 24 hours on healthy 7 DOHSS, and this process continued, till the death of the vector was attained.

3.3.3.5 Statistical analysis:

Complete Randomized Design (CRD)

Analysis of complete randomized design was applied as proposed by Sharma (2011) to know the inherent variability amongst all the treatments in the acquisition access period (AAP), inoculation access period (IAP) and effect of vector population on disease transmission. The analysis of variance of different observations has been presented in the Appendix-VI and the skeleton of ANOVA for CRD is given in the table below:

Skeleton of Analysis of Variance (ANOVA):

Sources of variation	df	SS	MSS	F cal	F table	
					5 %	1%
Treatments	t-1	SSt	MSSt=SSt/t-1	MSSt/MSSe		
Error	n-t	SSe	MSSe=SSe/n-t	-	-	
Total	n-1	TSS	-	-	-	

Where,

df = Degree of freedom

SS =Sum of squares

MSS =Mean sum of squares

F cal = F calculated

n = Total number of observations

t = Number of treatments

SSt = Sum of squares of treatments

SSe = Sum of squares of error

MSSt =Mean sum of squares due to treatments

MSSe = Mean sum of squares due to error

TSS = Total sum of squares

The 'F' test was applied to check the overall significance of various treatments in general and comparison of individual treatment was made with the help of critical difference at 5% level of significance which was calculated as given below:-

SEd for treatment = SEm ×√2

CD for treatment = SEd × "t" value at 5% error degree of freedom

Where,

SEm± = Standard error of treatment means

SEd = Standard error of difference between two treatments

CD = Critical difference

't' = t value at 5% level of error degree of freedom

RESULTS

The findings of the experiment on "Studies on whitefly, *Bemisia tabaci* Genn., vector of mungbean yellow mosaic India virus with special reference to seasonal fluctuation and virus-vector relationship in soybean" are described in this chapter under respective objectives.

3.1. To study the seasonal incidence of whitefly and yellow mosaic disease in soybean crop

3.1.1. Whitefly, *Bemisia tabaci* Genn. (Hemiptera: Aleyrodidae)

3.1.1.1 Post *Kharif* / *Rabi* season

3.1.1.1.a. First year (2014-15)

First appearance of whitefly on soybean was observed on 7 days old crop (DOC) [8th December, 2014 *i.e.* 49th SW (03/12/ 2014 to 09/12/2014)]. The number of adult whitefly was worked out as weekly average per plant or cage and the data are presented in Table 5, Appendix-I and illustrated in Fig. 1. From Fig. 1, it is evident that the whitefly population appeared on 7DOC (49th SW) and was available for 113 days *i.e.* till 119 DOC (13th SW, 26/03/2015 to 01/04/2015). Mean population over the season was 2.02 adult whiteflies/plant with ±0.11 standard error (SE).

Whitefly population attained its first peak on 49 DOC (1.30 adult whiteflies/plant) *i.e.* 3rd SW (15/01/2015 to 21/01/2015), when maximum temperature (Max T) and minimum temperature (Min T) was 22.20 and 5.30^{0}C, respectively, whereas morning relative humidity (Morn RH) and evening relative humidity (Even RH) were 91.00 and 37.00%, respectively. Further, wind speed (WS), sunshine (SS), morning vapour pressure (Morn VP), evening vapour pressure (Even VP) and evaporation (Evap) were 2.60 km/hr, 8.30 hrs, 7.30 mm, 7.30 mm and 1.70 mm, respectively. There was no rainfall (RF) received during this week.

Second peak (5.0 adult whiteflies/plant) was recorded on 84 DOC *i.e.* 8th SW (19/02/2015 to 25/02/2015), when Max T and Min T was 30.60 and 12.00^{0}C, respectively, whereas Morn RH and Even RH were 86.00 and 33.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were

1.90 km/hr, 9.70 hrs, 10.40 mm, 10.70 mm and 3.30 mm, respectively. There was no RF received during this week.

Third peak (4.40 adult whiteflies/plant) was observed on 112 DOC *i.e.* 12th SW (19/03/2015 to 25/03/2015), when Max T and Min T was 31.80 and 13.80^{0}C, respectively, whereas Morn RH and Even RH were 80.00 and 26.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 2.20 km/hr, 10.30 hrs, 11.40 mm, 9.50 mm and 4.00 mm, respectively. There was no RF received during this week.

Correlation studies:

Correlation studies revealed that Max T, Min T, Morn VP, Even VP, Evap and crop age had significant positive association (r= 0.54, 0.58, 0.58, 0.58, 0.55 and 0.85, respectively) with whitefly population (Table 6).

The regression equations being:

$\hat{Y}$ = - 3.10 + 0.19x (R^2 = 0.28)

$\hat{Y}$ = - 0.35 +0.22x (R^2 = 0.33)

$\hat{Y}$= - 1.72 + 0.38x (R^2 = 0.33)

$\hat{Y}$= - 1.46 + 0.36x (R^2 = 0.33)

$\hat{Y}$= 0.20 + 0.76x (R^2 = 0.30)

$\hat{Y}$= 0.22 + 0.04x (R^2 = 0.72)

The above equations, express that with every unit increase in Max T, Min T, Morn VP, Even VP, Evap and crop age, there was an increase of 0.19, 0.22, 0.38, 0.36, 0.76 and 0.04 adult whitefly population/plant.

Correlation studies further revealed that the WS, SS and RF exhibited positive correlation (r= 0.01, 0.39 and 0.04, respectively) with whitefly population, but statistically found to be non-significant (Table 6).

Further, Morn RH showed significant negative correlation (r= -0.48) with whitefly population (Table 6).

The regression equation being:

$\hat{Y}$ = 20.76-0.21x (R^2 = 0.23)

The above equation express that with every unit increase in Morn RH there was a decrease of 0.21 adult whitefly population/plant. While, Even RH exhibited negative correlation (r= -0.17) with whitefly population, but statistically found to be non-significant (Table 6).

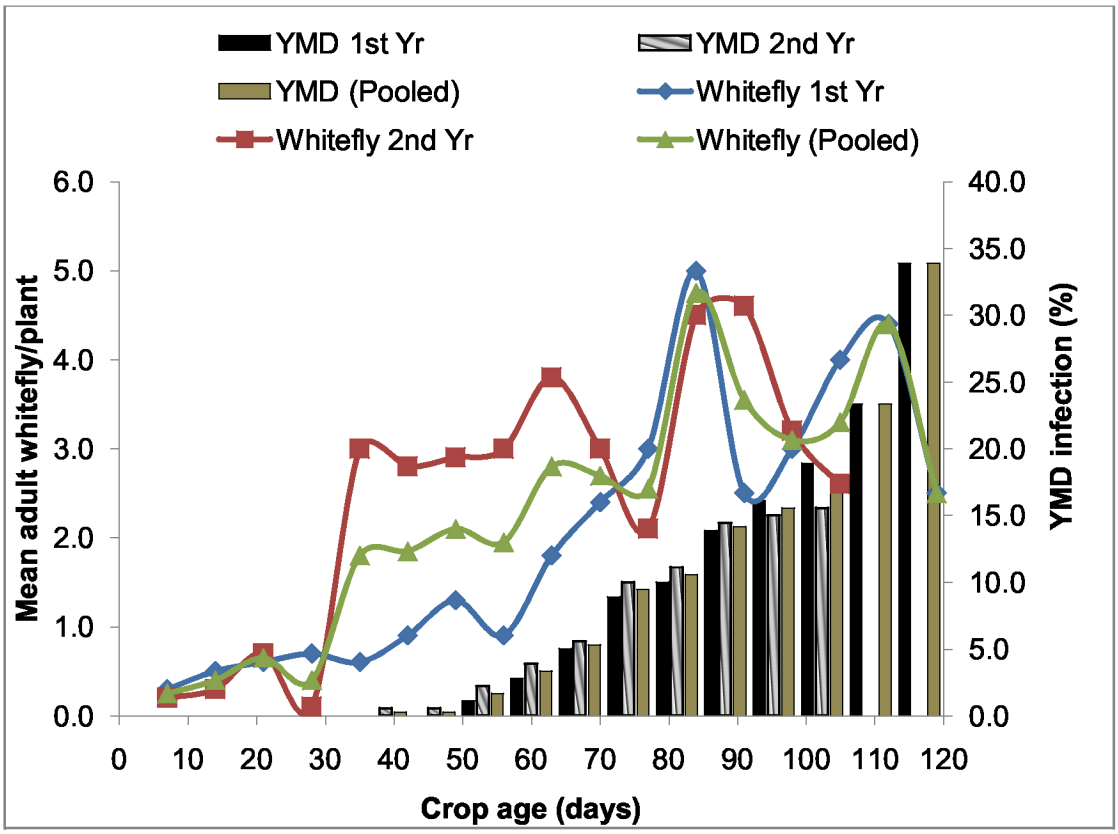

Fig 1: Influence of crop age on incidence of whitefly, *B. tabaci* and YMD infection on *rabi* soybean

Table 5: Incidence of whitefly, *Bemisia tabaci* infesting soybean

Crop age (days)	Mean adult whitefly population / plant on soybean planted in different seasons								
	Rabi			Summer			*Kharif*		
	2014-15	2015-16	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
7	0.30 (0.89)	0.20 (0.84)	0.25 (0.87)	2.30 (1.67)	0.80 (1.14)	1.55 (1.43)	1.80 (1.52)	0.10 (0.77)	0.95 (1.20)
14	0.50 (1.00)	0.30 (0.89)	0.40 (0.95)	4.80 (2.30)	1.60 (1.45)	3.20 (1.92)	2.50 (1.73)	2.40 (1.70)	2.45 (1.72)
21	0.60 (1.05)	0.70 (1.10)	0.65 (1.07)	6.20 (2.59)	3.80 (2.07)	5.00 (2.35)	2.40 (1.70)	4.50 (2.24)	3.45 (1.99)
28	0.70 (1.10)	0.10 (0.77)	0.40 (0.95)	9.00 (3.08)	5.90 (2.53)	7.45 (2.82)	6.00 (2.55)	10.50 (3.32)	8.25 (2.96)
35	0.60 (1.05)	3.00 (1.87)	1.80 (1.52)	12.20(3.56)	8.50 (3.00)	10.35 (3.29)	3.40 (1.97)	8.40 (2.98)	5.90 (2.53)
42	0.90 (1.18)	2.80 (1.82)	1.85 (1.53)	10.50(3.32)	10.30 (3.29)	10.40 (3.30)	5.20 (2.39)	5.00 (2.35)	5.10 (2.37)
49	1.30 (1.34)	2.90 (1.84)	2.10 (1.61)	12.00(3.54)	12.80 (3.65)	12.40 (3.59)	6.60 (2.66)	2.10 (1.61)	4.35 (2.20)
56	0.90 (1.18)	3.00 (1.87)	1.95 (1.57)	14.50(3.87)	10.10 (3.26)	12.30 (3.58)	11.20 (3.42)	10.40 (3.30)	10.80 (3.36)
63	1.80 (1.52)	3.80 (2.07)	2.80 (1.82)	8.60 (3.02)	15.30 (3.97)	11.95 (3.53)	13.40 (3.73)	14.80 (3.91)	14.10 (3.82)
70	2.40 (1.70)	3.00 (1.87)	2.70 (1.79)	7.00 (2.74)	8.40 (2.98)	7.70 (2.86)	9.00 (3.08)	9.50 (3.16)	9.25 (3.12)
77	3.00 (1.87)	2.10 (1.61)	2.55 (1.75)	#	5.80 (2.51)	5.80 (2.51)	8.50 (3.00)	6.20 (2.59)	7.35 (2.80)
84	5.00 (2.35)	4.50 (2.24)	4.75 (2.29)	-	3.30 (1.95)	3.30 (1.95)	7.50 (2.83)	4.30 (2.19)	5.90 (2.53)
91	2.50 (1.73)	4.60 (2.26)	3.55 (2.01)	-	0.40 (0.95)	0.40 (0.95)	6.40 (2.63)	0.20 (0.84)	3.30 (1.95)
98	3.00 (1.87)	3.20 (1.92)	3.10 (1.90)	-	#	-	#	#	-
105	4.00 (2.12)	2.60 (1.76)	3.30 (1.95)	-	-	-	-	-	-
112	4.40 (2.21)	#	4.40 (2.21)	-	-	-	-	-	-
119	2.50 (1.73)	-	2.50 (1.73)	-	-	-	-	-	-
	#	-	-	-	-	-	-	-	-
Mean	2.02 (1.52)	2.45 (1.65)	2.30 (1.62)	8.71 (2.97)	6.69 (2.52)	7.06 (2.62)	6.45 (2.55)	6.03 (2.38)	6.24 (2.50)
SE±	(±0.11)	(±0.13)	(±0.11)	(±0.21)	(±0.27)	(±0.24)	(±0.19)	(±0.27)	(±0.20)
Duration of availability (in days)	113	98	-	64	85	-	85	85	-
t cal.	0.74 NS		-	0.71 NS		-	0.53 NS		-
				Pooled - *Rabi vs* Summer			Pooled - *Rabi vs Kharif*		
t cal.	-	-	-	-	-	4.15*	-	-	4.17*
Pooled - Summer *vs Kharif*									
t cal.	-	-	-	-	-	-	-	-	0.38 NS

Signifies that the crop has matured,
Figures in parentheses are √x+0.5 transformed values,
SE±=Standard error, NS=Non-significant, *= Significant at 5%

Table 6: Correlation (r) and regression coefficient (byx) of abiotic factors and crop age on whitefly infesting soybean planted in different seasons

Weather factors	*Rabi*						Summer						*Kharif*					
	2014-15		2015-16		Pooled		2015-16		2016-17		Pooled		2015-16		2016-17		Pooled	
	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx
Max. temp.(°C)	0.54*	0.19	0.66**	0.19	0.66**	0.23	0.74*	0.88	0.55*	0.67	0.51 NS	-	0.56*	1.37	0.31 NS	-	0.39 NS	-
Min. temp.(°C)	0.58*	0.22	0.61*	0.20	0.50*	0.08	0.65*	0.70	0.20 NS	-	0.24 NS	-	-0.18 NS	-	-0.18 NS	-	0.07 NS	-
Morning RH (%)	-0.48*	-0.21	-0.40 NS	-	0.10 NS	-	-0.66*	-0.20	-0.67**	-0.19	-0.67*	-0.21	-0.005 NS	-	-0.73**	-1.62	-0.37 NS	-
Evening RH (%)	-0.17 NS	-	-0.36 NS	-	-0.03 NS	-	-0.56 NS	-	-0.77**	-0.31	-0.78**	-0.36	-0.42 NS	-	-0.49 NS	-	-0.34 NS	-
Wind speed (km/hr)	0.01 NS	-	0.39 NS	-	0.32 NS	-	0.38 NS	-	-0.05 NS	-	-0.14 NS	-	-0.59*	-1.16	-0.29 NS	-	-0.43 NS	-
Sunshine (hrs)	0.39 NS	-	0.39 NS	-	0.42 NS	-	-0.12 NS	-	0.65*	3.54	0.47 NS	-	0.59*	0.82	0.42 NS	-	0.52 NS	-
Morning VP (mm)	0.58*	0.38	0.59*	0.37	0.46 NS	-	-0.05 NS	-	-0.62*	-1.20	-0.60*	-1.18	-0.11 NS	-	-0.23 NS	-	0.06 NS	-
Evening VP (mm)	0.58*	0.36	0.13 NS	-	0.41 NS	-	-0.22 NS	-	-0.71**	-0.96	-0.73**	-1.11	-0.18 NS	-	-0.28 NS	-	0.03 NS	-
Evaporation (mm)	0.55*	0.76	0.55*	0.45	0.51*	0.28	0.64*	1.50	0.64*	1.20	0.52 NS	-	0.59*	5.23	0.43 NS	-	0.45 NS	-
Rainfall (mm)	0.04 NS	-	0.06 NS	-	0.25 NS	-	-0.05 NS	-	-0.63*	-0.28	-0.69**	-0.35	-0.63*	-0.04	-0.21 NS	-	-0.43 NS	-
Crop age (days)	0.85**	0.04	0.75**	0.04	0.85**	0.03	0.58 NS	-	0.16 NS	-	0.01 NS	-	0.68**	0.09	0.15 NS	-	0.42 NS	-

NS= Non-significant, *= Significant at 5%, **= Significant at 1%

Table 7: Multiple regression of abiotic factors and crop age on whitefly infesting soybean planted in different seasons

Season	Constant	Max. temp. (°C)	Min. temp. (°C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm)	Evaporation (mm)	Rainfall (mm)	Crop age (days)	R^2
Rabi 2014-15	-19.127	0.347	0.078	0.152				-0.640	0.284	-0.574		0.046	0.876
Rab 2015-16i	-0.920	0.268	0.260					-0.697		-1.698		0.094	0.783
Pooled	0.727	-0.017	-0.025							0.004		0.038	0.743
Summer 15-16	-31.513	1.123	-0.122	0.009						-0.214			0.559
Summer 16-17	4.282	0.139		0.463	-0.677		-2.518	-1.690	0.927	2.870	0.081		0.839
Pooled	27.188			-0.329	0.587			1.030	-2.813		-0.040		0.781
Kharif 2015-16	23.430	-0.790				-0.394	-0.088			2.415	-0.024	0.062	0.614
Kharif 2016-17	153.992			-1.621									0.540

Path coefficient analysis:

Path coefficient analysis measures the direct and indirect effects of total correlation coefficient of one variable through another, the end product was carried out by using correlation value by keeping whitefly population as dependent variable over the weather factors.

Path coefficient analysis revealed that the Morn VP had highest positive direct effect (1.5965) on whitefly population followed by Even VP (1.0992), Max T (0.7178) and SS (0.5626), respectively. However, Min T had the maximum negative direct effect (-1.9181) followed by Evap (-0.3853), Even RH (-0.2058), Morn RH (-0.1277) on whitefly population, respectively (Table 8).

Morn VP had maximum positive indirect effect on whitefly population through Even VP (0.8586) followed by Max T (0.3578), Morn RH (0.0550) while, it had negative indirect effect on whitefly population via Min T (-1.8914), SS (-0.1545), Evap (-0.1441), Even RH (-0.0627), RF (-0.0240) and WS (-0.0130), respectively.

Even VP had maximum positive indirect effect on whitefly population via Morn VP (1.2470), Max T (0.0174) and Morn RH (0.0074), while it exerted maximum negative indirect effect through Min T (-1.3912) followed by SS (-0.2168), Even RH (-0.1295), RF (-0.0325), WS (-0.0166) and Evap (-0.0063), respectively.

Max T exhibited positive indirect effect on whitefly population through Morn VP (0.7958) followed by SS (0.2282), Even RH (0.1218), Morn RH (0.0934), Even VP (0.0266), RF (0.0137) and WS (0.0050), while it had negative indirect effect through Min T (-1.1240) and Evap (-0.3409), respectively.

SS exhibited the highest positive indirect effect on whitefly population through Min T (0.3592) followed by Max T (0.2912), Even and Morn RH (0.1688 and 0.0588, respectively), RF (0.0245) and WS (0.0140), while it had maximum negative effect through Morn VP (-0.4384) followed by Even VP (-0.4236) and Evap (-0.2293), respectively.

Min T had the highest negative direct effect on whitefly population, which had indirect positive effect through Morn VP (1.5743) followed by Even VP (0.7973), Max T (0.4206) and Morn RH (0.0664), respectively. While it had the highest indirect effect via Evap (-0.1815) followed by SS (-0.1053), Even RH (-0.0439), RF (-0.0220) and WS (-0.0120), respectively.

Higher R^2 (0.876) value and low residual effect (0.2456) were obtained from multiple regression with significant independent factors (Table 7) and path analysis (Table 8), respectively indicated that the weather parameters selected for the study were appropriate and were responsible for almost 88% variation in the whitefly population.

3.1.1.1.b. Second year (2015-16)

First appearance of whitefly on soybean was observed on 7 DOC [1st January, 2016 *i.e.* 1st SW (01/01/2016 to 07/01/2016)]. The number of adult whitefly was worked out as weekly average per plant or cage and the data are presented in Table 5, Appendix-II and illustrated in Fig. 1. It is evident from Fig. 1 that the whitefly population appeared on 7 DOC (1st SW) and was available for 99 days *i.e.* 105 DOC (15th SW, 09/04/2016 to 15/04/2016). Mean population over the season was 2.45 adult whiteflies/plant with SE ±0.13.

Whitefly population attained its first peak (3.00 adult whiteflies/plant) on 35 DOC *i.e.* 5th SW (29/01/2016 to 04/02/2016), when Max T and Min T was 27.70 and 9.10^{0}C, respectively, whereas Morn RH and Even RH were 92.00 and 35.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 2.80 km/hr, 9.30 hrs, 8.90 mm, 9.30 mm and 2.50 mm, respectively. There was no RF received during this week.

Second peak (3.80 adult whiteflies/plant) was observed on 63 DOC *i.e.* 9th SW (26/02/2016 to 04/03/2016), when Max T and Min T was 30.50 and 13.40^{0}C, respectively, whereas Morn RH and Even RH were 85.00 and 34.00%, respectively. Further, WS, SS, Morn VP and Even VP and Evap were 3.30 km/hr, 8.50 hrs, 10.70 mm, 11.00 mm and 2.80 mm, respectively. However, no RF received during this week.

Third peak (4.60 adult whiteflies/plant) was recorded on 91 DOC *i.e.* 13th SW (26/03/2016 to 01/04/2016), when Max T and Min T was 35.80 and 16.40^{0}C, respectively, whereas Morn RH and Even RH were 78.00 and 17.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 2.30 km/hr, 10.00 hrs, 12.90 mm, 7.10 mm and 4.70 mm, respectively. RF received during this week was 8.00 mm.

Correlation studies:

Correlation studies revealed that the Max T, Min T, Morn VP, Evap and crop age exhibited positive association (r= 0.66, 0.61, 0.59, 0.55 and 0.75, respectively) with whitefly population (Table 6).

The regression equations being:

$\hat{Y}$ = - 3.41 + 0.19x (R^2 = 0.44)

$\hat{Y}$ = - 0.02 + 0.20x (R^2 = 0.37)

$\hat{Y}$ = - 1.49 + 0.37x (R^2 = 0.35)

$\hat{Y}$ = 0.89 + 0.45x (R^2 = 0.30)

$\hat{Y}$ = 0.46 + 0.04x (R^2 = 0.57)

The above equation, express that with every unit increase in Max T, Min T, Morn VP, Evap and crop age, there was an increase of 0.19, 0.20, 0.37, 0.45 and 0.04 adult whitefly/plant.

Correlation studies further revealed that WS, SS, Even VP and RF exhibited positive correlation (r= 0.39, 0.39, 0.13 and 0.06, respectively) with whitefly population, but statistically found to be non-significant (Table 6).

While Morn RH and Even RH exhibited negative correlation (r= -0.40 and -0.36, respectively) with whitefly population, but statistically non-significant (Table 6).

Path coefficient analysis:

Path coefficient analysis revealed that Max T had highest positive direct effect (6.6861) on whitefly population followed by Even RH (1.9791), Morn RH (1.9618), WS (1.0789) and RF (0.3837), respectively. However, Morn VP had the maximum negative direct effect (-2.4967) followed by Even VP (-1.2277), Evap (-0.9436), SS (-0.5556) and Min T (-0.5011) on whitefly population, respectively (Table 9).

Table 8: Direct and indirect effect of abiotic components on adult whitefly population infesting *rabi* soybean (2014-15)

Weather factors	Max. temp.(°C)	Min. temp.(°C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm)	Evaporation (mm)	Rainfall (mm)	" r "
Max. temp.(°C)	**0.7178**	-1.1240	0.0934	0.1218	0.0050	0.2282	0.7958	0.0266	-0.3409	0.0137	0.54*
Min. temp.(°C)	0.4206	**-1.9181**	0.0664	-0.0439	-0.0120	-0.1053	1.5743	0.7973	-0.1815	-0.0220	0.58*
Morning RH (%)	-0.5247	0.9970	**-0.1277**	-0.1084	-0.0035	-0.2588	-0.6880	-0.0637	0.3016	-0.0068	-0.48*
Evening RH (%)	-0.4250	-0.4095	-0.0673	**-0.2058**	-0.0155	-0.4616	0.4862	0.6919	0.2645	-0.0327	-0.17
Wind speed (km/hr)	-0.1376	-0.8804	-0.0173	-0.1225	**-0.0260**	-0.3022	0.7967	0.6993	0.0330	-0.0300	0.01
Sunshine (hrs)	0.2912	0.3592	0.0588	0.1688	0.0140	**0.5626**	-0.4384	-0.4236	-0.2293	0.0245	0.39
Morning VP (mm)	0.3578	-1.8914	0.0550	-0.0627	-0.0130	-0.1545	**1.5965**	0.8586	-0.1441	-0.0240	0.58*
Evening VP (mm)	0.0174	-1.3912	0.0074	-0.1295	-0.0166	-0.2168	1.2470	**1.0992**	-0.0063	-0.0325	0.58*
Evaporation (mm)	0.6350	-0.9034	0.1000	0.1413	0.0022	0.3348	0.5969	0.0180	**-0.3853**	0.0152	0.55*
Rainfall (mm)	-0.1723	-0.7402	-0.0151	-0.1177	-0.0137	-0.2416	0.6696	0.6254	0.1025	**-0.0571**	0.04

Residual effect = 0.2456

*= Significant at 5%, " r " = Correlation coefficients of adult whitefly with weather factors, Diagonal values (bold) indicated direct effects.

Table 9: Direct and indirect effect of abiotic components on adult whitefly population infesting *rabi* soybean (2015-16)

Weather factors	Max. temp.(°C)	Min. temp.(°C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm)	Evaporation (mm)	Rainfall (mm)	" r "
Max. temp.(°C)	**6.6861**	-0.4402	-1.6642	-1.4018	0.3004	-0.3329	-1.8043	0.2093	-0.8867	-0.0014	0.66**
Min. temp.(°C)	5.8737	**-0.5011**	-1.3968	-0.6018	0.6008	-0.1423	-2.3286	-0.2333	-0.7826	0.1233	0.61*
Morning RH (%)	-5.6718	0.3568	**1.9618**	1.4095	-0.2557	0.3067	1.0741	-0.5408	0.8752	0.0843	-0.40
Evening RH (%)	-4.7357	0.1524	1.3972	**1.9791**	0.2535	0.4772	0.1563	-0.9019	0.6683	0.1961	-0.36
Wind speed (km/hr)	1.8614	-0.2791	-0.4650	0.4651	**1.0789**	0.0355	-1.4785	-0.5705	-0.3708	0.1154	0.39
Sunshine (hrs)	4.0063	-0.1283	-1.0827	-1.6996	-0.0689	**-0.5556**	-0.1823	0.7987	-0.5968	-0.1032	0.39
Morning VP (mm)	4.8320	-0.4674	-0.8440	-0.1239	0.6389	-0.0406	**-2.4967**	-0.5541	-0.5877	0.2025	0.59*
Evening VP (mm)	-1.1400	-0.0952	0.8642	1.4538	0.5014	0.3615	-1.1267	**-1.2277**	0.2792	0.2551	0.13
Evaporation (mm)	6.2829	-0.4156	-1.8196	-1.4016	0.4240	-0.3514	-1.5549	0.3633	**-0.9436**	-0.0312	0.55*
Rainfall (mm)	-0.0241	-0.1610	0.4310	1.0115	0.3246	0.1494	-1.3180	-0.8164	0.0766	**0.3837**	0.06

Residual effect = 0.5321

*= Significant at 5%, ** = Significant at 1%, " r " = Correlation coefficients of adult whitefly with weather factors,

Diagonal values (bold) indicated direct effects.

Table 10: Direct and indirect effect of abiotic components and crop age on adult whitefly population infesting *rabi* soybean (Pooled)

Weather factors	Max. temp.(°C)	Min. temp.(°C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm)	Evaporation (mm)	Rainfall (mm)	Crop age	" r "
Max. temp.(°C)	**-4.0659**	-6.9517	-3.2494	0.1222	-0.2654	1.7146	13.6125	0.4979	1.2094	-0.0299	-1.9327	0.66**
Min. temp.(°C)	-2.9407	**-9.6115**	-9.1105	-0.7038	-0.5536	2.4889	20.1353	0.9699	1.5233	-0.0921	-1.6077	0.50*
Morning RH (%)	-1.2110	-8.0266	**-10.9094**	-0.9161	-0.5439	2.4987	17.6246	0.9296	1.3059	-0.0470	-0.6052	0.10
Evening RH (%)	0.4015	-5.4657	-8.0751	**-1.2376**	-0.4582	1.0956	12.4196	0.8184	0.6466	-0.1260	-0.0495	-0.03
Wind speed (km/hr)	-1.7755	-8.7556	-9.7636	-0.9332	**-0.6077**	2.2709	18.8049	0.9946	1.3489	-0.1085	-1.1563	0.32
Sunshine (hrs)	-2.4105	-8.2715	-9.4252	-0.4688	-0.4772	**2.8921**	17.5238	0.8261	1.4803	-0.0133	-1.2388	0.42
Morning VP (mm)	-2.7379	-9.5736	-9.5114	-0.7604	-0.5653	2.5071	**20.2151**	0.9927	1.5168	-0.0913	-1.5295	0.46
Evening VP (mm)	-1.9261	-8.8701	-9.6496	-0.9637	-0.5751	2.2733	19.0932	**1.0510**	1.3535	-0.0963	-1.2758	0.41
Evaporation (mm)	-3.1114	-9.2647	-9.0149	-0.5064	-0.5187	2.7091	19.4024	0.9001	**1.5804**	-0.0441	-1.6236	0.51*
Rainfall (mm)	-0.4077	-2.9708	-1.7214	-0.5235	-0.2212	0.1287	6.1963	0.3398	0.2341	**-0.2980**	-0.5103	0.25
Crop stage (days)	-3.3309	-6.5498	-2.7986	-0.0259	-0.2979	1.5187	13.1060	0.5683	1.0876	-0.0644	**-2.3592**	0.85**

Residual effect =0.2055

*= Significant at 5%, "r" = Correlation coefficients of adult whitefly with weather factors, Diagonal values (bold) indicated direct effects.

Max T had the highest positive indirect effect on whitefly population through WS (0.3004) followed by Even VP (0.2093) while, it had maximum negative indirect effect on whitefly population via Morn VP (-1.8043) followed by Morn RH (-1.6642), Even RH (-1.4018), Evap (-0.8867), Min T (-0.4402), SS (-0.3329) and RF (-0.0014), respectively.

Even RH had maximum positive indirect effect on whitefly population via Morn RH (1.3972), Evap (0.6683), SS (0.4772), WS (0.2535), RF (0.1961), Morn VP (0.1563) and Min T (0.1524), while it exerted maximum negative indirect effect through Max T (-4.7357) followed by Even VP (-0.9019), respectively.

Morn RH exhibited positive indirect effect through Even RH (1.4095) on whitefly population followed by Morn VP (1.0741), Evap (0.8752), Min T (0.3568), SS (0.3067) and RF (0.0843), while it had maximum negative indirect effect via Max T (-5.6718) followed by Even VP (-0.5408) and WS (-0.2557), respectively.

Morn VP had the highest negative direct effect on whitefly population, had indirect positive effect through Max T (4.8320) followed by WS (0.6389) and RF (0.2025), respectively, while it had the highest negative indirect effect via Morn RH (-0.8440) followed by Evap (-0.5877), Even VP (-0.5541), Min T (-0.4674), Even RH (-0.1239) and SS (-0.0406), respectively.

Higher R^2 (0.783) value and low residual effect (0.5321) were obtained from multiple regression with significant independent factors (Table 7) and path analysis (Table 9), respectively indicated that the weather parameters selected for the study were appropriate and were responsible for almost 78% variation in the whitefly population.

3.1.1.1.c. Pooled data

During first and second year of study, the first appearance of whitefly on soybean was observed on 7 DOC *i.e.* 49th SW (03/12/2014 to 09/12/2014) and 1st SW (01/01/2016 to 07/01/2016), respectively and were available upto the crop maturity stage. The number of adult whitefly was worked out as weekly average per plant or cage and the data are presented in Table 5 and illustrated in Fig.1. The mean whitefly population of both the years were found

to be non-significant. However, mean population during *rabi* season was 2.30 adult whiteflies/plant with SE ±0.11.

Whitefly population attained its first peak (2.10 adult whiteflies/plant) and second peak (4.75 adult whiteflies/plant) on 49 and 84 DOC, respectively.

Correlation studies:

Correlation studies revealed that the Max T, Min T, Evap and crop age had significant positive correlation (r= 0.66, 0.50, 0.51 and 0.85, respectively) with whitefly population (Table 6).

The regression equations computed were:

$\hat{Y} = - 4.36 + 0.23x$ ($R^2 = 0.44$)

$\hat{Y} = - 1.17 + 0.08x$ ($R^2 = 0.25$)

$\hat{Y} = 1.32 + 0.28 x$ ($R^2 = 0.26$)

$\hat{Y} = 0.25 + 0.03x$ ($R^2 = 0.73$)

The above equations it can be interpret that with every unit increase in Max T, Min T, Evap and crop age, there was an increase of 0.23, 0.08, 0.28 and 0.03 adult whitefly/plant (Fig. 2, 3, 4 and 5, respectively).

Correlation studies further revealed that the Morn RH, WS, Morn and Even VP, and RF exhibited positive association (r= 0.10, 0.32, 0.42, 0.46 and 0.25, respectively) with whitefly population, but was statistically non-significant (Table 6).

While Even RH expressed negative correlation (r= -0.03) with whitefly population, but statistically found to be non-significant (Table 6).

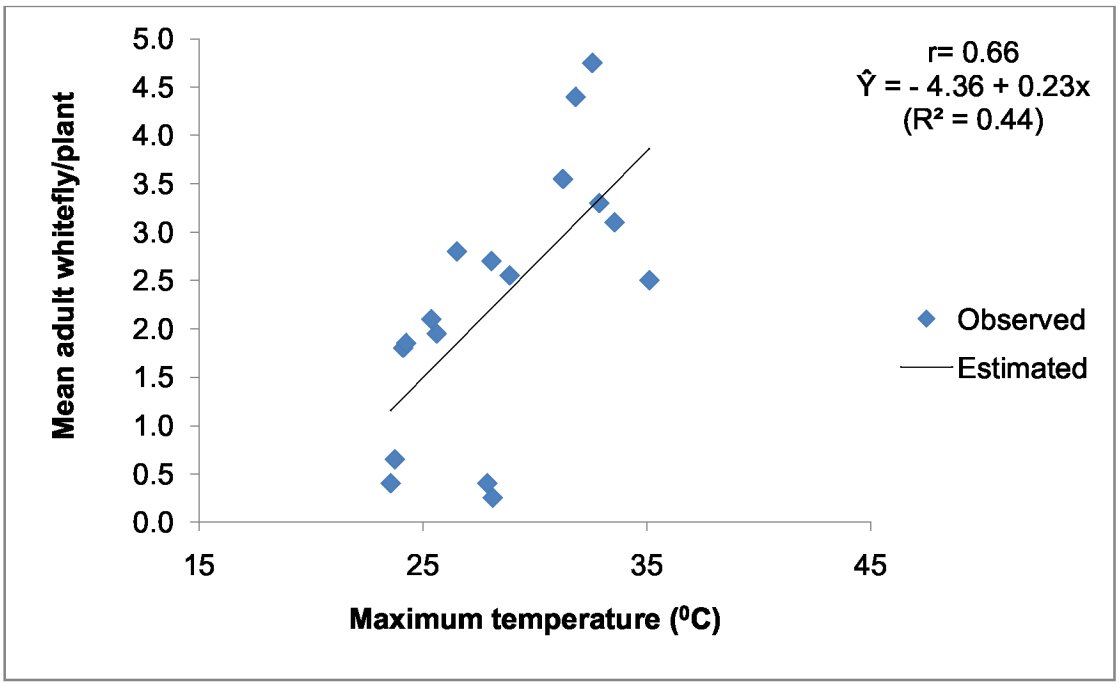

Fig. 2: Regression of whitefly infesting *rabi* soybean on maximum temperature (Pooled)

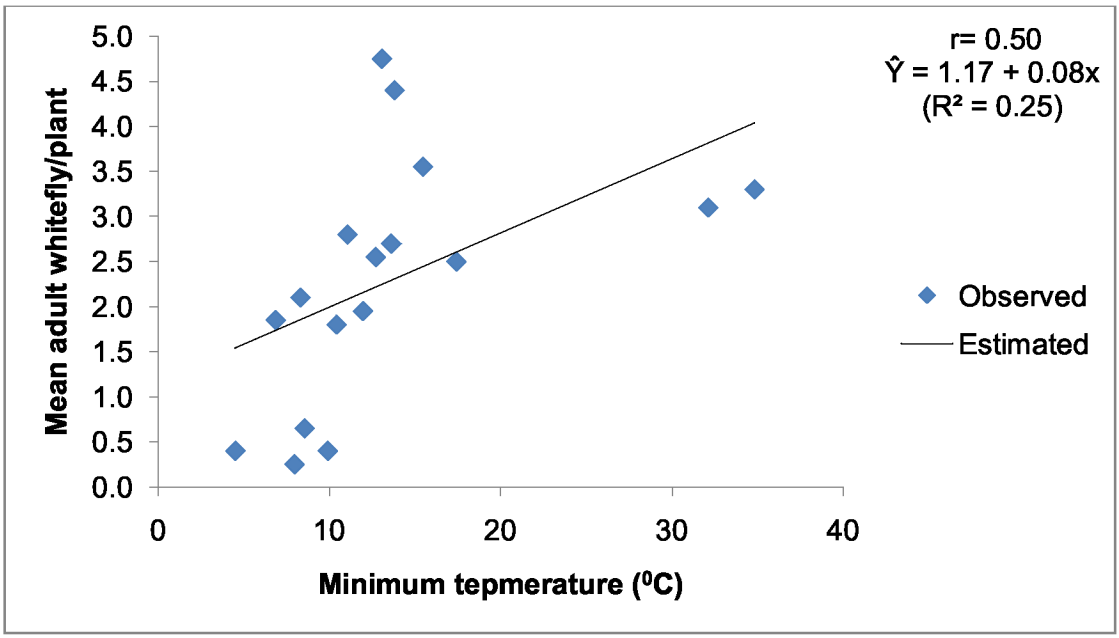

Fig. 3: Regression of whitefly infesting *rabi* soybean on minimum temperature (Pooled)

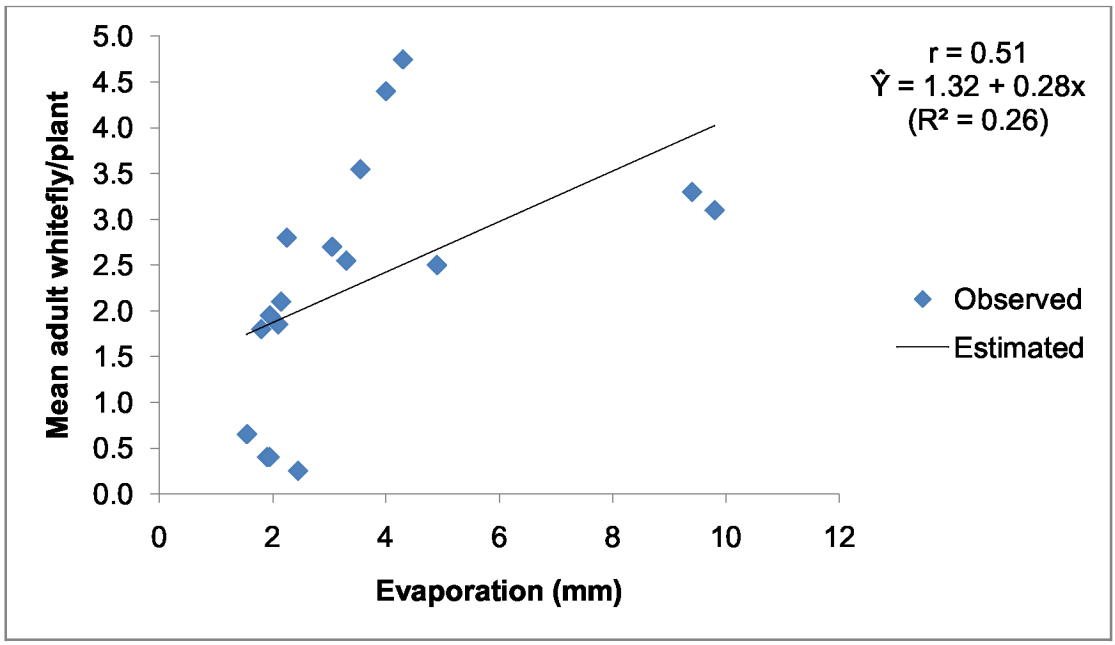

Fig. 4: Regression of whitefly infesting *rabi* soybean on evaporation (Pooled)

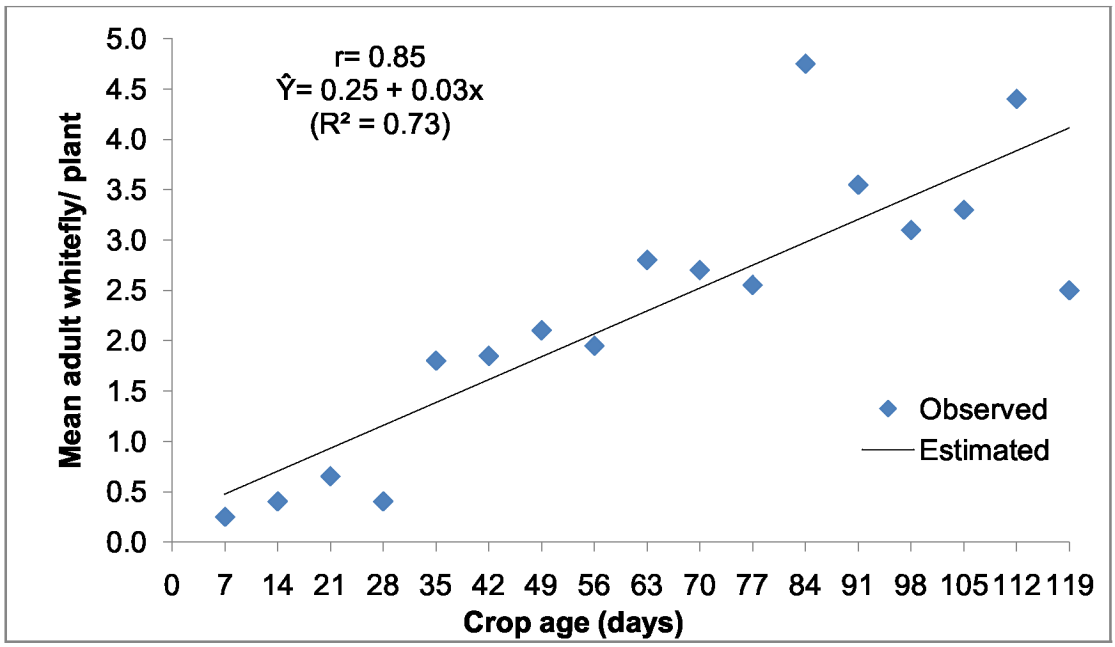

Fig. 5: Regression of whitefly infesting *rabi* soybean on crop age (Pooled)

Path coefficient analysis:

Path coefficient analysis revealed that the Morn VP had the highest positive direct effect (20.2151) on whitefly population followed by SS (2.8921), Evap (1.5804), Even VP (1.0510), respectively. However, Morn RH had the negative maximum direct effect (-10.9094) followed by Min T (-9.6115), Max T (-4.0659), crop age (-2.3592), Even RH (-1.2376), WS (-0.6077) and RF (-0.2980), respectively (Table 10).

Morn VP had the highest positive indirect effect on whitefly population through SS (2.5071), followed by Evap (1.5168) and Even VP (0.9927), while it had maximum negative indirect effect via Min T (-9.5736) followed by Morn RH (-9.5114), Max T (-2.7379), crop age (-1.5295), Even RH (-0.7604), WS (-0.5653) and RF (-0.0913), respectively.

SS had positive indirect effect on whitefly population through Morn VP (17.5238), Evap (1.4803) and Even VP (0.8261), respectively, while it had maximum negative indirect effect via Morn RH (-9.4252), Min T (-8.2715) followed by Max T (-2.4105), crop age (-1.2388), WS (-0.4772), Even RH (-0.4688) and RF (-0.0133), respectively.

Morn RH had the highest negative direct effect on whitefly population, which had the highest positive indirect effect via Morn VP (17.6246) followed by SS (2.4987), Evap (1.3059) and Even VP (0.9296), respectively, while it had maximum negative indirect effect via Min T (-8.0266) followed by Max T (-1.2110), Even RH (-0.9161), crop age (-0.6052) and RF (-0.0470), respectively.

Higher R^2 (0.743) and low residual effect (0.2055) obtained from multiple regression with significant independent factors (Table 7) and path analysis (Table 10), respectively indicated that the weather parameters selected for the study were appropriate and were responsible for almost 74% variation in the whitefly population.

3.1.1.2 Summer season

3.1.1.2.a. First year (2015-16)

First appearance of whitefly on soybean was observed on7 DOC [6th April, 2015 *i.e.* 14th SW (02/04/2015 to 08/04/2015)]. The number of adult

whitefly was worked out as weekly average per plant or cage and the data are presented in Table 5, Appendix-I and illustrated in Fig. 6. It is evident from Fig. 6 that the whitefly population appeared on 7 DOC (14th SW) and was available for 64 days *i.e.* 70 DOC (23rd SW, 04/06/2015 to 10/06/2015). Mean population over the season was 8.71 adult whiteflies/plant with SE ±0.21.

Whitefly population attained its first peak (12.20 adult whiteflies/plant) on 35 DOC *i.e.* 18th SW (30/04/2015 to 06/05/2015), when Max T and Min T was 40.40 and 23.50^{0}C, respectively, whereas Morn RH and Even RH were 44.00 and 14.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 4.70 km/hr, 8.30 hrs, 12.00 mm, 7.40 mm and 7.40 mm, respectively during the study period. There was no RF received during this week.

Second peak (14.50 adult whiteflies/plant) was observed on 56 DOC *i.e.* 21st SW (21/05/2015 to 27/05/2015), when Max T and Min T was 42.80 and 27.50^{0}C, respectively, whereas Morn RH and Even RH were 37.00 and 16.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 6.90 km/hr, 9.40 hrs, 13.20 mm, 10.20 mm and 10.90 mm, respectively. There was 6.20 mm RF received during this week.

Correlation analysis:

Correlation studies revealed that the Max T, Min T and Evap exhibited significant positive association (r= 0.74, 0.65 and 0.64, respectively) with whitefly population (Table 6).

The regression equations being:

$\hat{Y} = - 25.91 + 0.88x$ ($R^2 = 0.55$)

$\hat{Y} = - 7.97 + 0.70x$ ($R^2 = 0.43$)

$\hat{Y} = - 3.27 + 1.50x$ ($R^2 = 0.41$)

The above equations express that with every unit increase in Max T, Min T and Evap there was an increase of 0.88 (Fig. 7), 0.70 and 1.50 adult whitefly population/plant.

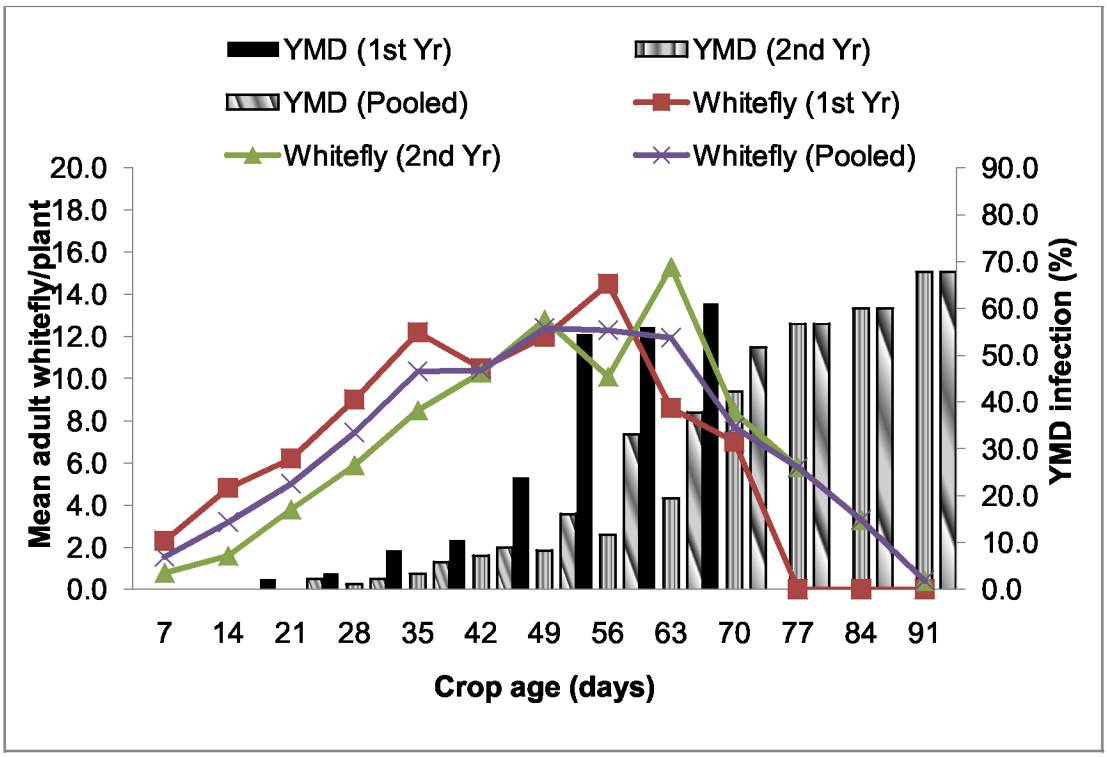

Fig. 6: Influence of crop age on incidence of whitefly, *B. tabaci* and YMD infection on summer soybean

Correlation studies further revealed that WS and crop age exhibited positive correlation (r= 0.38 and 0.58, respectively) with whitefly population, but statistically found to be non-significant (Table 6).

Further, Morn RH showed significant negative correlation (r= -0.66) with whitefly population (Table 6).

The regression equation being:

$\hat{Y} = 18.42 - 0.20x$ ($R^2 = 0.43$)

The above equation express that with every unit increase in Morn RH, there was a decrease of 0.20 adult whitefly population/plant. While Even RH, SS, Morn VP, Even VP and RF showed negative correlation (r= -0.56, -0.12, -0.05, -0.22 and -0.05, respectively) with whitefly population, but statistically found to be non-significant (Table 6).

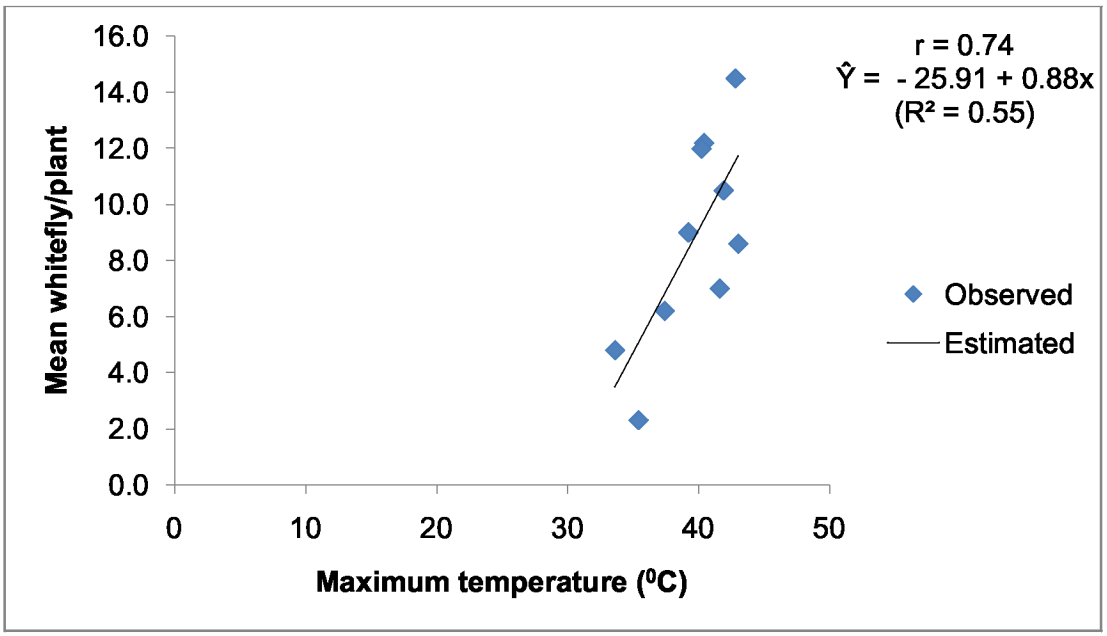

Fig. 7: Regression of whitefly infesting summer soybean on maximum temperature (2015-16)

Path coefficient analysis:

Path coefficient analysis revealed that Morn RH had positive and high direct effect (25.8223) on whitefly population followed by Max T (25.1461), Even VP (20.5802), WS (9.7582) and RF (2.9368), respectively. However Even RH had the maximum negative direct effect (-29.4273) followed by Min T (-14.9214), Morn VP (-14.0762), Evap (-11.9801) and SS (-3.7813), respectively (Table 11).

Morn RH had the highest positive indirect effect on whitefly population through Min T (11.1060) followed by Evap (10.2681), Even VP (6.7627), RF (1.3136) and SS (1.1627) while, it had highest negative indirect effect on whitefly population via Even RH (-24.4688) followed by Max T (-22.4077), Morn VP (-5.5136) and WS (-4.7044), respectively.

Max T had the highest positive indirect effect on whitefly population through Even RH (22.5501) followed by WS (3.9384) while, it had maximum negative indirect effect on whitefly population via Morn RH (-23.0103) followed by Min T (-13.5606), Evap (-10.6731), Even VP (-2.2041), RF (-1.1257), SS (-0.3025) and Morn VP (-0.0141), respectively.

Even VP had the highest positive indirect effect on whitefly population through Morn RH (8.4852), WS (4.5073), SS (1.8215) and RF (0.6761),

respectively, while it had highest negative indirect effect via Even RH (-18.8658) followed by Morn VP (-10.2010), Min T (-4.1108), Max T (-2.6931.) and Evap (-0.4193), respectively.

Even RH had the highest positive indirect effect via Morn RH (21.4712) on whitefly population followed by Even VP (13.1940), Evap (7.6900), Min T (7.5204), RF (1.7603) and SS (1.7084), respectively, while it had highest negative indirect effect via Max T (-19.2695) followed by Morn VP (-4.8253) and WS (-0.3854), respectively.

Higher R^2 (0.559) and low residual effect (0.0914) obtained from multiple regression with significant independent factors (Table 7) and path analysis (Table 11), respectively indicated that the weather parameters selected for the study were appropriate and were responsible for almost 56% variation in the whitefly population.

3.1.1.2.b. Second year (2016-17)

First appearance of whitefly was observed on soybean on 7 DOC [8th March, 2016 *i.e.* 10th SW (05/03/2016 to 11/03/2016)] and the data are presented in Table 5, Appendix-II and illustrated in Fig. 6. From Fig. 6, it is evident that the whitefly population appeared on 7 DOC (10th SW) and was available 91 DOC *i.e.* 85 days (22nd SW, 28/05/2016 to 03/06/2016). Mean population over the season was 6.69 adult whiteflies/plant with SE ±0.27.

Whitefly population attained its first peak (12.80 adult whiteflies/plant) on 49 DOC *i.e.* 16th SW (16/04/2016 to 22/04/2016), when Max T and Min T was 41.10 and 21.90^{0}C, respectively, whereas Morn RH and Even RH were 48.00 and 12.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 5.00 km/hr, 10.50 hrs, 11.70 mm, 7.10 mm and 8.80 mm, respectively. There was no RF received during this week.

Second peak (15.30 adult whiteflies/plant) was observed on 63 DOC *i.e.*18th SW (30/04/2016 to 06/05/2016), when Max T and Min T was 41.50 and 22.70^{0}C, respectively, whereas Morn RH and Even RH were 38.00 and 14.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 6.90 km/hr, 9.80 hrs, 10.90 mm, 7.80 mm and 10.70 mm, respectively. There was 3.20 mm RF received during this week.

Correlation studies:

Correlation studies revealed that Max T, SS and Evap showed significant positive association (r= 0.55, 0.65 and 0.64, respectively) with whitefly population (Table 6).

The regression equations computed were:

$\hat{Y}$ = - 18.84 + 0.67x (R^2 = 0.31)

$\hat{Y}$ = - 26.60 + 3.54x (R^2 = 0.42)

$\hat{Y}$= - 2.15 + 1.20x (R^2 = 0.41)

From the above equations it may be said that with every unit increase in Max T, SS and Evap, there was an increase of 0.67 (Fig. 8), 3.54, and 1.20 adult whitefly population/plant.

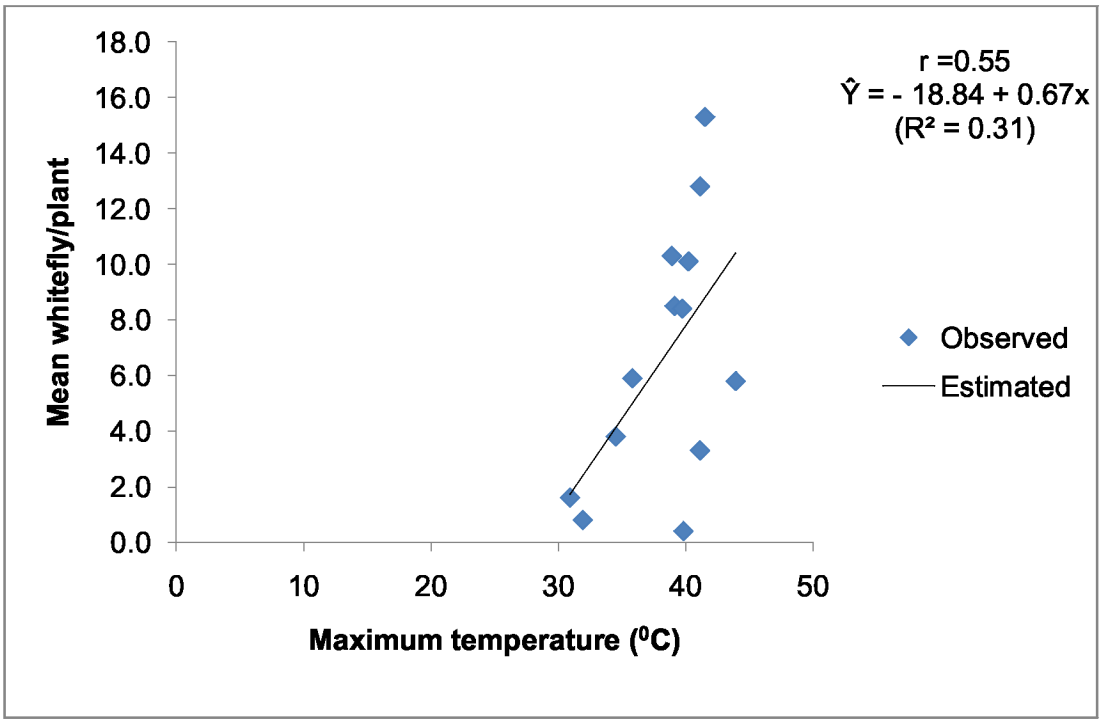

Fig. 8: Regression of whitefly infesting summer soybean on maximum temperature (2016-17)

Correlation studies further revealed that Min T and crop age exhibited positive correlation (r= 0.20 and 0.16, respectively) with whitefly population, but statistically found to be non-significant (Table 6).

Further Morn RH, Even RH, Morn VP, Even VP and RF showed significant negative correlation (r= -0.67, -0.77, -0.62, -0.71 and -0.63, respectively) with whitefly population (Table 6).

The regression equations being:

$\hat{Y}$ =17.61 - 0.19x (R^2 = 0.46)

$\hat{Y}$=13.47 - 0.31x (R^2 = 0.59)

$\hat{Y}$=22.69 - 1.20x (R^2 = 0.39)

$\hat{Y}$=16.18 - 0.96x (R^2 = 0.51)

$\hat{Y}$=8.76 - 0.28x (R^2 = 0.40)

The above equation express that with every unit increase in Morn RH, Even RH, Morn VP, Even VP and RF, there was decrease of 0.19, 0.31, 1.20, 0.96 and 0.28 adult whitefly population/plant.

Path coefficient analysis:

Path coefficient analysis showed that the Max T had positive and high direct effect (0.9735) on whitefly population followed by WS (0.7486) and RF (0.6542), respectively. However, Even VP had the highest negative direct effect (-2.1074) followed by Evap (-1.3560), SS (-1.1740), Morn RH (-0.7028), Morn VP (-0.4675) Even RH (-0.0816) and Min T (-0.0757) on whitefly population, respectively (Table 12).

Table 11: Direct and indirect effect of abiotic components on adult whitefly population infesting summer soybean (2015-16)

Weather factors	Max. temp.(°C)	Min. temp.(°C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm)	Evaporation (mm)	Rainfall (mm)	" r "
Max. temp.(°C)	**25.1461**	-13.5606	-23.0103	22.5501	3.9384	-0.3025	-0.0141	-2.2041	-10.6731	-1.1257	0.74*
Min. temp.(°C)	22.8528	**-14.9214**	-19.2195	14.8314	6.1281	0.4613	-3.9090	5.6698	-10.2909	-0.9486	0.65*
Morning RH (%)	-22.4077	11.1060	**25.8223**	-24.4688	-4.7044	1.1627	-5.5136	6.7627	10.2681	1.3136	-0.66**
Evening RH (%)	-19.2695	7.5204	21.4712	**-29.4273**	-0.3854	1.7084	-4.8253	13.1940	7.6900	1.7603	-0.56
Wind speed (km/hr)	10.1490	-9.3706	-12.4489	1.1624	**9.7582**	-0.2647	-0.2210	9.5060	-7.9536	0.0611	0.38
Sunshine (hrs)	2.0117	1.8204	-7.9404	13.2953	0.6831	**-3.7813**	7.8869	-9.9135	-3.9127	-0.2702	-0.12
Morning VP (mm)	0.0251	-4.1437	10.1146	-10.0877	0.1532	2.1187	**-14.0762**	14.9145	0.8745	0.0611	-0.05
Evening VP (mm)	-2.6931	-4.1108	8.4852	-18.8658	4.5073	1.8215	-10.2010	**20.5802**	-0.4193	0.6761	-0.22
Evaporation (mm)	22.4027	-12.8175	-22.1323	18.8894	6.4785	-1.2350	1.0276	0.7203	**-11.9801**	-0.7166	0.64*
Rainfall (mm)	-9.6385	4.8196	11.5503	-17.6387	0.2030	0.3479	-0.2928	4.7376	2.9231	**2.9368**	-0.05

Residual effect =0.0914

*= Significant at 5%, ** = Significant at 1%, " r " = Correlation coefficients of adult whitefly with weather factors,

Diagonal values (bold) indicated direct effects.

Table 12: Direct and indirect effect of abiotic components on adult whitefly population infesting summer soybean (2016-17)

Weather factors	Max. temp.(°C)	Min. temp.(°C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm)	Evaporation (mm)	Rainfall (mm)	" r "
Max. temp.(°C)	**0.9735**	-0.0659	0.6503	0.0476	0.4281	-0.3338	-0.0517	0.3610	-1.2520	-0.2031	0.55*
Min. temp.(°C)	0.8476	**-0.0757**	0.5334	0.0118	0.5631	0.2161	-0.2188	-0.6295	-1.0969	0.0444	0.20
Morning RH (%)	-0.9008	0.0574	**-0.7028**	-0.0538	-0.3913	0.4420	-0.0770	-0.6748	1.3085	0.3179	-0.67**
Evening RH (%)	-0.5676	0.0110	-0.4630	**-0.0816**	0.1222	1.0351	-0.2607	-1.8456	0.7123	0.5702	-0.77**
Wind speed (km/hr)	0.5568	-0.0569	0.3674	-0.0133	**0.7486**	0.3271	-0.2235	-0.9635	-0.9180	0.2291	0.05
Sunshine (hrs)	0.2768	0.0139	0.2646	0.0720	-0.2085	**-1.1740**	0.3145	1.9533	-0.3668	-0.4966	0.65*
Morning VP (mm)	0.1076	-0.0354	-0.1158	-0.0455	0.3578	0.7898	**-0.4675**	-1.7449	0.0900	0.4432	-0.62*
Evening VP (mm)	-0.1668	-0.0226	-0.2250	-0.0715	0.3422	1.0882	-0.3871	**-2.1074**	0.2711	0.5666	-0.71**
Evaporation (mm)	0.8989	-0.0612	0.6782	0.0429	0.5068	-0.3176	0.0310	0.4213	**-1.3560**	-0.2048	0.64*
Rainfall (mm)	-0.3023	-0.0051	-0.3415	-0.0711	0.2621	0.8911	-0.3167	-1.8252	0.4246	**0.6542**	-0.63*

Residual effect =0.3855

*= Significant at 5%, ** = Significant at 1%, " r " = Correlation coefficients of adult whitefly with weather factors,

Diagonal values (bold) indicated direct effects.

Table 13: Direct and indirect effect of abiotic components and crop age on adult whitefly population infesting summer soybean (Pooled)

Weather factors	Max. temp.(°C)	Min. temp.(°C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm)	Evaporation (mm)	Rainfall (mm)	Crop age (days)	" r "
Max. temp.(°C)	**-1.1420**	-0.1621	3.2323	0.0339	1.1127	-0.0967	0.1075	0.1567	-1.9423	0.1201	-0.9086	0.51
Min. temp.(°C)	-1.0407	**-0.1778**	2.7598	0.0142	1.6011	0.0237	0.3782	-0.4055	-1.8479	-0.0185	-1.0417	0.24
Morning RH (%)	1.0806	0.1437	**-3.4161**	-0.0416	-0.7046	0.1435	0.1698	-0.4881	1.9609	-0.2204	0.7008	-0.67*
Evening RH (%)	0.6492	0.0424	-2.3851	**-0.0596**	0.8595	0.2863	0.5243	-1.2845	0.9162	-0.4386	0.1143	-0.78**
Wind speed (km/hr)	-0.5567	-0.1247	1.0545	-0.0224	**2.2824**	0.1357	0.6165	-1.0607	-1.2789	-0.3309	-0.8541	-0.14
Sunshine (hrs)	-0.3031	0.0116	1.3452	0.0468	-0.8502	**-0.3643**	-0.5427	1.1780	-0.4723	0.3079	0.1100	0.47
Morning VP (mm)	-0.1279	-0.0701	-0.6046	-0.0326	1.4667	0.2061	**0.9594**	-1.3191	-0.0171	-0.3433	-0.7201	-0.60*
Evening VP (mm)	0.1167	-0.0470	-1.0877	-0.0499	1.5792	0.2800	0.8256	**-1.5330**	0.1177	-0.4448	-0.4818	-0.73**
Evaporation (mm)	-1.0483	-0.1553	3.1657	0.0258	1.3795	-0.0813	0.0078	0.0852	**-2.1160**	0.0737	-0.8135	0.52
Rainfall (mm)	0.2695	-0.0065	-1.4795	-0.0514	1.4840	0.2204	0.6471	-1.3398	0.3066	**-0.5089**	-0.2299	-0.69**
Crop stage (days)	-0.9222	-0.1646	2.1275	0.0061	1.7325	0.0356	0.6140	-0.6564	-1.5299	-0.1040	**-1.1252**	0.01

Residual effect =0.1201

*= Significant at 5%, "r" = Correlation coefficients of adult whitefly with weather factors, Diagonal values (bold) indicated direct effects.

Max T had maximum positive indirect effect on whitefly population through Morn RH (0.6503) followed by WS (0.4281), Even VP (0.3610) and Even RH (0.0476), while it had highest negative indirect effect via Evap (-1.2520) followed by SS (-0.3338), RF (-0.2031), Min T (-0.0659) and Morn VP (-0.0517), respectively.

WS had maximum positive indirect effect on whitefly population through Max T (0.5568) followed by Morn RH (0.3674), SS (0.3271) and RF (0.2291), respectively, while it had highest negative indirect effect via Even VP (-0.9635) followed by Evap (-0.9180), Morn VP (-0.2235), Min T (-0.0569) and Even RH (-0.0133), respectively.

Even VP had the highest indirect effect on whitefly population through SS (1.0882) followed by RF (0.5666), WS (0.3422) and Evap (0.2711), respectively, while it had highest negative indirect effect via Morn VP (-0.3871) followed by Morn RH (-0.2250), Even RH (-0.0715), Max T (-0.1668) and Min T (-0.0226), respectively.

Higher R^2 (0.839) and low residual effect (0.3855) obtained from multiple regression with significant independent factors (Table 7) and path analysis (Table 12), respectively indicated that the weather parameters selected for the study were appropriate and were responsible for almost 84% variation in the whitefly population.

3.1.1.2.c. Pooled data

During first and second year of study, the first appearance of whitefly on soybean was observed on 7 DOC *i.e.* 14th SW (02/04/2015 to 08/04/2015) and 10th SW (05/03/2016 to 11/03/2016), respectively (Table 5 and Fig. 6). The mean population of both the years were found to be no-significant. However, mean population during summer season was 7.06 adult whiteflies / plant with SE ±0.24.

Only one peak (12.40 adult whiteflies/plant) was recorded on soybean *i.e.* on 49 DOC and thereafter the population gradually declined.

Correlation studies:

Correlation studies revealed that Max T, Min T, SS, Evap and crop age showed positive association (r= 0.01) with whitefly population, but statistically found to be non-significant (Table 6).

However, Morn and Even RH, Morn and Even VP and RF showed significant negative correlation (r= -0.67, -0.78, -0.60, -0.73 and -0.69, respectively) with whitefly population (Table 6).

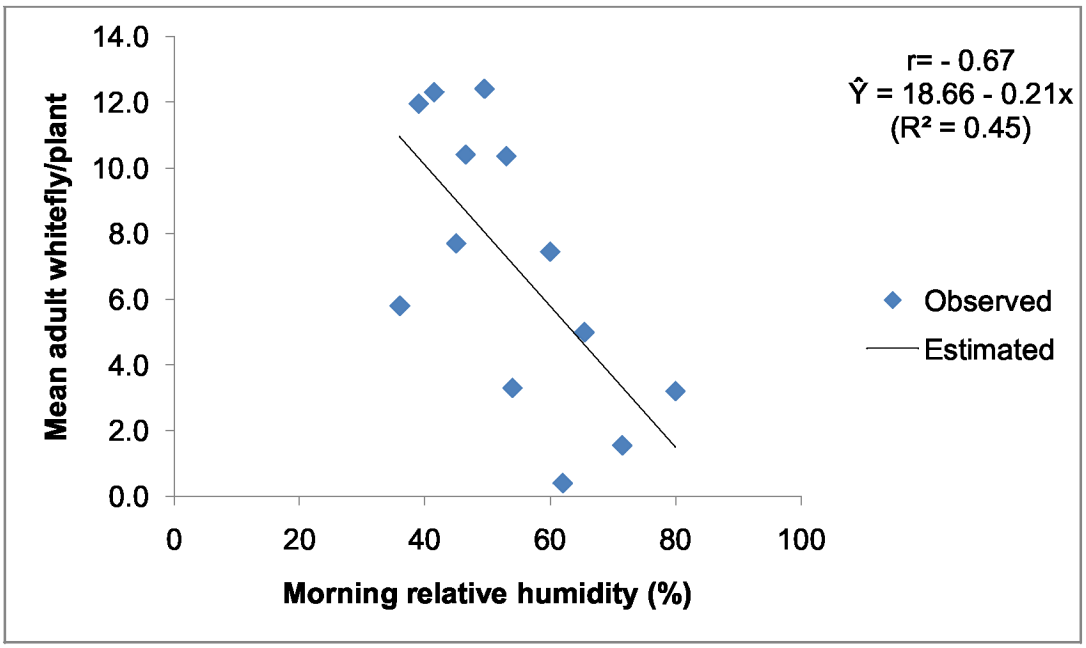

Fig. 9: Regression of whitefly infesting summer soybean on morning relative humidity (Pooled)

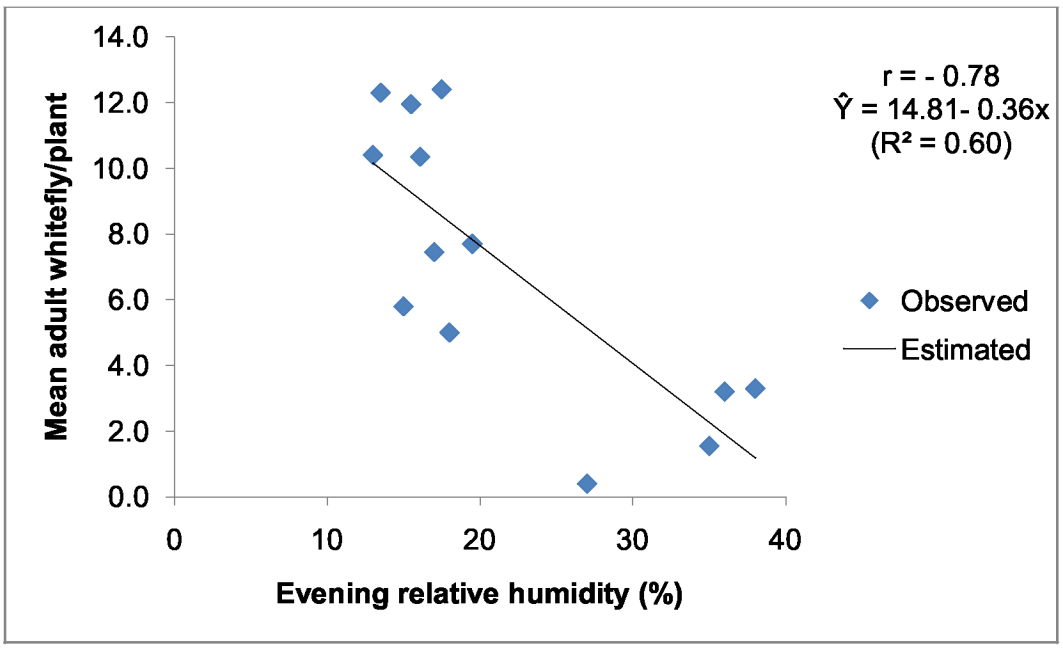

Fig.10: Regression of whitefly infesting summer soybean on evening relative humidity (Pooled)

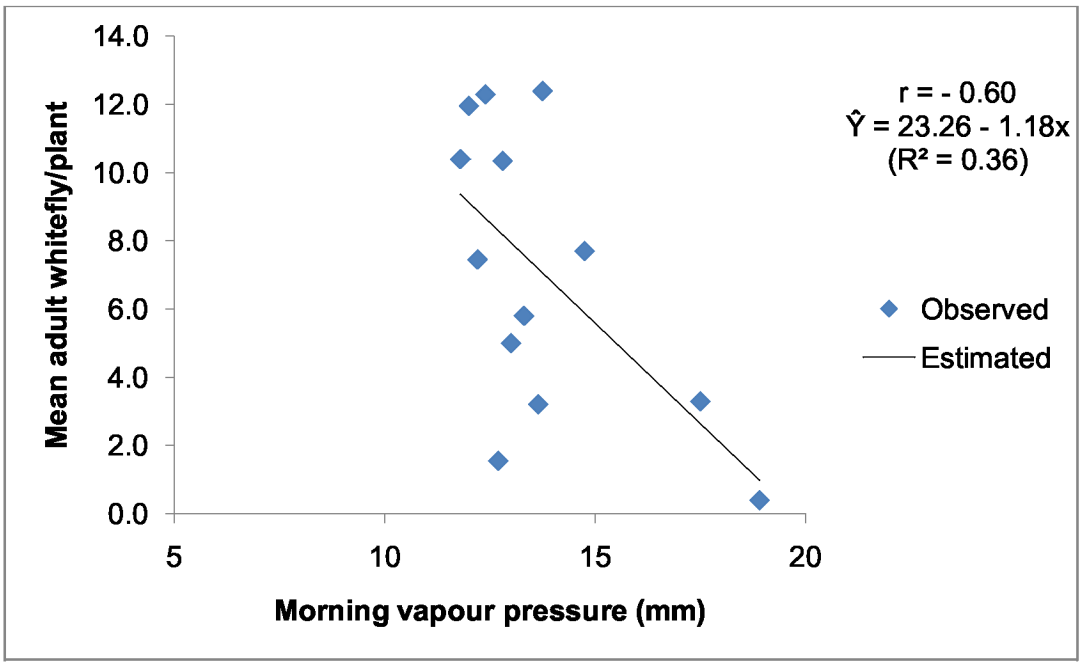

Fig. 11: Regression of whitefly infesting summer soybean on morning vapour pressure (Pooled)

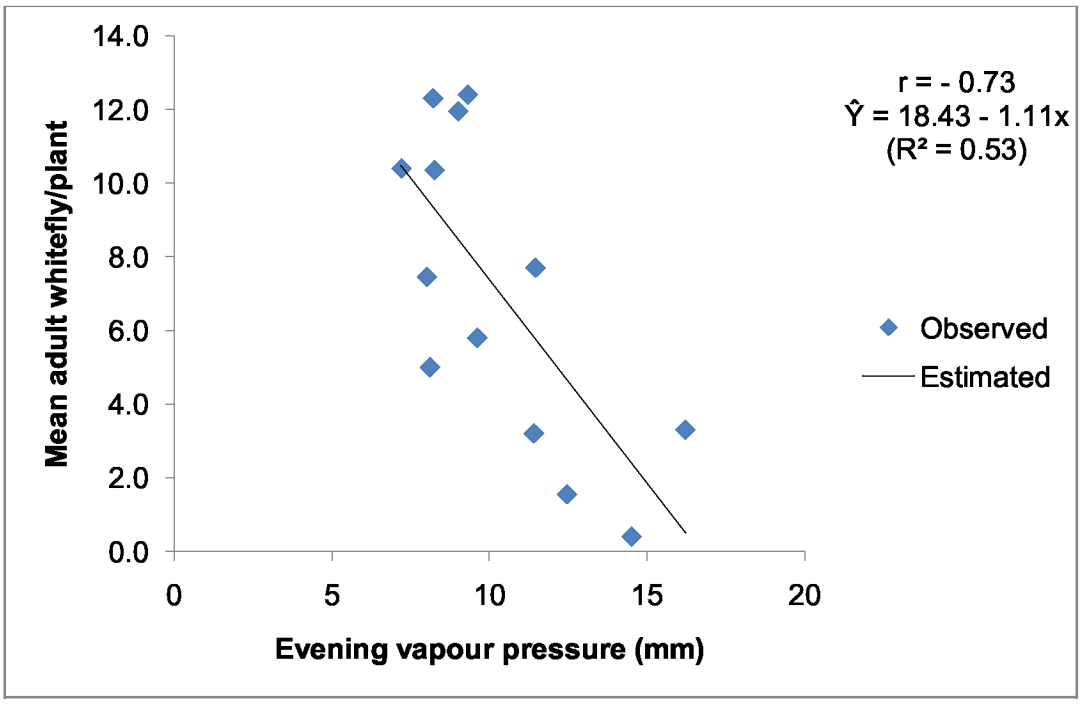

Fig. 12: Regression of whitefly infesting summer soybean on morning vapour pressure (Pooled)

The regression equations computed were:

$\hat{Y}$ = 18.66 - 0.21x (R^2 = 0.45)

$\hat{Y}$ = 14.81- 0.36x (R^2 = 0.60)

$\hat{Y}$ = 23.26 -1.18x (R^2 = 0.36)

$\hat{Y}$ = 18.43 -1.11x (R^2 = 0.53)

$\hat{Y}$ = 9.32 - 0.35x (R^2 = 0.47)

The above equations, express that with every unit increase in Morn and Even RH, Morn and Even VP and RF there was a decrease of 0.21, 0.36, 1.18, 1.11 and 0.35 whitefly population/plant (Fig. 9, 10, 11, 12 and 13, respectively).

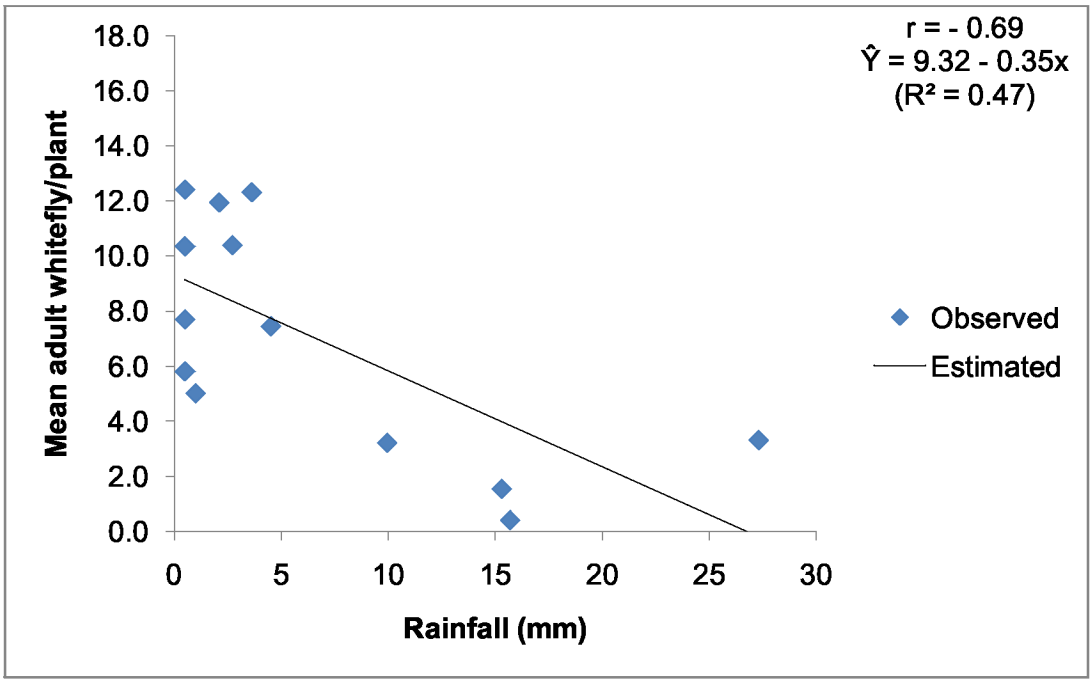

Fig.13: Regression of whitefly infesting summer soybean on rainfall (Pooled)

Path coefficient analysis:

Path coefficient analysis revealed that WS had the highest positive direct effect (2.2824) on whitefly population followed by Morn VP (0.9594), while Morn RH had highest negative direct effect (-3.4161), followed by Evap (-2.1160), Even VP (-1.5330), Max T (-1.1420), crop age (-1.1252), RF (-

0.5089), SS (-0.3643), Min T (-0.1778), Even RH (-0.0596), respectively (Table 13).

WS had the highest positive indirect effect on whitefly population through Morn RH (1.0546) followed by Morn VP (0.6165) and SS (0.1357), respectively, while it had highest negative indirect effect via Evap (-1.2789) followed by Even VP (-1.0607), crop age (-0.8541), Max T (-0.5567), RF (-0.3309), Min T (-0.1247) and Even RH (-0.0224), respectively.

Morn VP had maximum positive indirect effect on whitefly population through WS (1.4667) followed by SS (0.2061), while it had highest negative indirect effect via Even VP (-1.3191) followed by crop age (-0.7201), Morn RH (-0.6046), RF (-0.3433), Max T (-0.1279), Min T (-0.0701), Even RH (-0.0326) and Evap (-0.0171), respectively.

Morn RH had maximum negative direct effect on whitefly population through maximum positive indirect effect Evap (1.9609) followed by Max T (1.0806), crop age (0.7008), Morn VP (0.1698), Min T (0.1437) and SS (0.1435), respectively, whereas it had highest and negative indirect effect via WS (-0.7046) followed by Even VP (-0.4881), RF (-0.2204) and Even RH (-0.0416), respectively.

Higher R^2 (0.781) value and low residual effect (0.1201) obtained from multiple regression with significant independent factors (Table 7) and path analysis (Table 13), respectively indicated that the weather parameters selected for the study were appropriate and were responsible for almost 78% variation in the whitefly population.

3.1.1.3 *Kharif* season

3.1.1.3.a First year (2015-16)

First appearance of whitefly on soybean was observed on 7 DOC [20th July, 2015 *i.e.* 29th SW (16/07/2015 to 22/07/2015)] and the data are presented in Table 5, Appendix-I and illustrated in Fig. 14. It is evident from Fig. 14, that the whitefly population appeared on 7 DOC *i.e.* 29th SW and was available for 85 days *i.e.* 91 DOC (41st SW, 08/10/2015 to 14/10/2015). Mean population over the season was 6.45 adult whiteflies/plant with SE ±0.19.

Whitefly population attained its first peak (2.50 adult whiteflies/plant) on 14 DOC *i.e.* 30th SW (23/07/2015 to 29/07/2015), when Max T and Min T was 30.60 and 23.50^{0}C, respectively, whereas Morn RH and Even RH were 87.00 and 67.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 5.40 km/hr, 4.50 hrs, 21.50 mm, 20.80 mm and 3.00 mm, respectively. There was 84.70 mm RF received during this week.

Second peak (6.0 adult whiteflies/plant) was observed on 28 DOC *i.e.* 32nd SW (06/08/2015 to 12/08/2015), when Max T and Min T was 31.20 and 24.20^{0}C, respectively, whereas Morn RH and Even RH were 91.00 and 69.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 3.70 km/hr, 4.60 hrs, 23.10 mm, 23.70 mm and 3.60 mm, respectively. There was 14.00 mm RF received during this week.

Third peak (13.40 adult whiteflies/plant) was recorded on 63 DOC *i.e.* 37th SW (10/09/2015 to 16/09/2015), when Max T and Min T was 33.50 and 23.10^{0}C, respectively, whereas Morn RH and Even RH were 91.00 and 55.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 3.10 km/hr, 8.40 hrs, 22.30 mm, 21.20 mm and 4.00 mm, respectively. There was 3.40 mm RF received during this week.

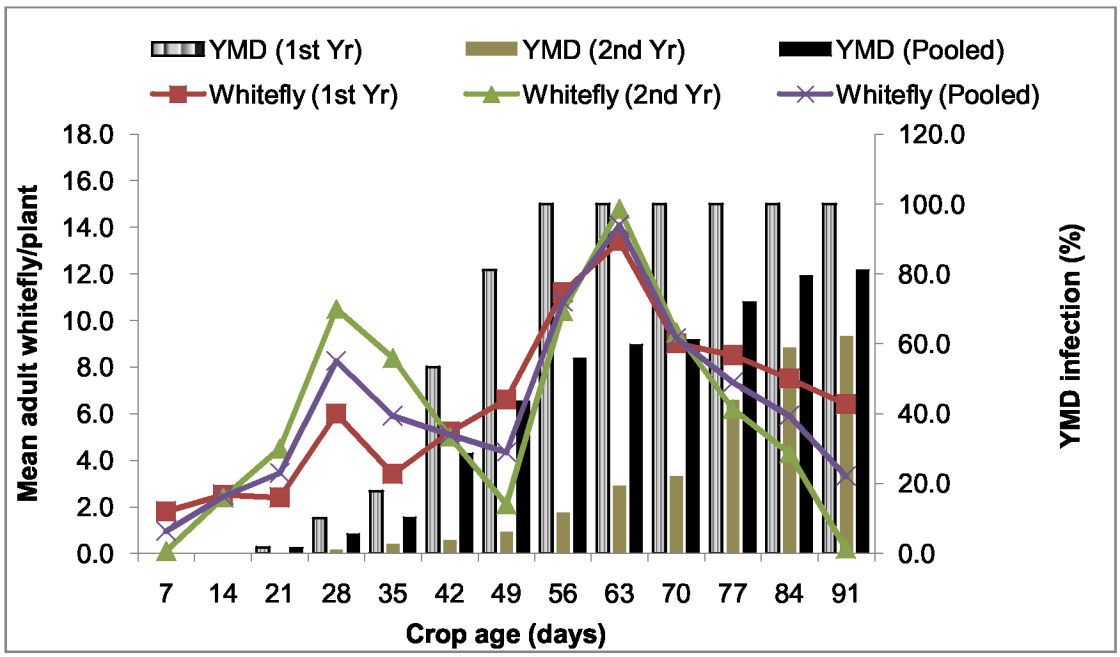

Fig. 14: Influence of crop age on incidence of whitefly, *B. tabaci* and YMD infection on *kharif* soybean

Correlation studies:

Correlation studies revealed that Max T, SS, Evap and crop age showed significant positive association (r= 0.56, 0.59, 0.59 and 0.68, respectively) with whitefly population (Table 6).

The regression equations being:

$\hat{Y}$ = - 37.23 + 1.37x (R^2 = 0.31)

$\hat{Y}$ = 1.47 + 0.82x (R^2 = 0.35)

$\hat{Y}$ = - 12.47 + 5.23x (R^2 = 0.35)

$\hat{Y}$ = 2.15 + 0.09x (R^2 = 0.47)

The above equations express that with every unit increase in Max T, SS, Evap and crop age, there was an increase of 1.37, 0.82, 5.23 and 0.09 adult whitefly population/plant (Fig. 15, 16, 17 and 18, respectively).

Further, WS and RF showed significant negative correlation (r= -0.59 and -0.63, respectively) with whitefly population (Table 6).

The regression equations being:

$\hat{Y}$= 11.85 - 1.16x (R^2 = 0.34)

$\hat{Y}$ = 8.47 - 0.04x (R^2 = 0.39)

The above equations express that with every unit increase in WS and RF there was a decrease of 1.16 and 0.04 adult whitefly population/plant (Fig. 19 and 20, respectively).

While Min T, Morn RH, Even RH, Morn VP and Even VP exhibited negative association (r= -0.18, -0.005, -0.42, -0.11 and -0.18, respectively) with whitefly population, but statistically found to be non-significant (Table 6).

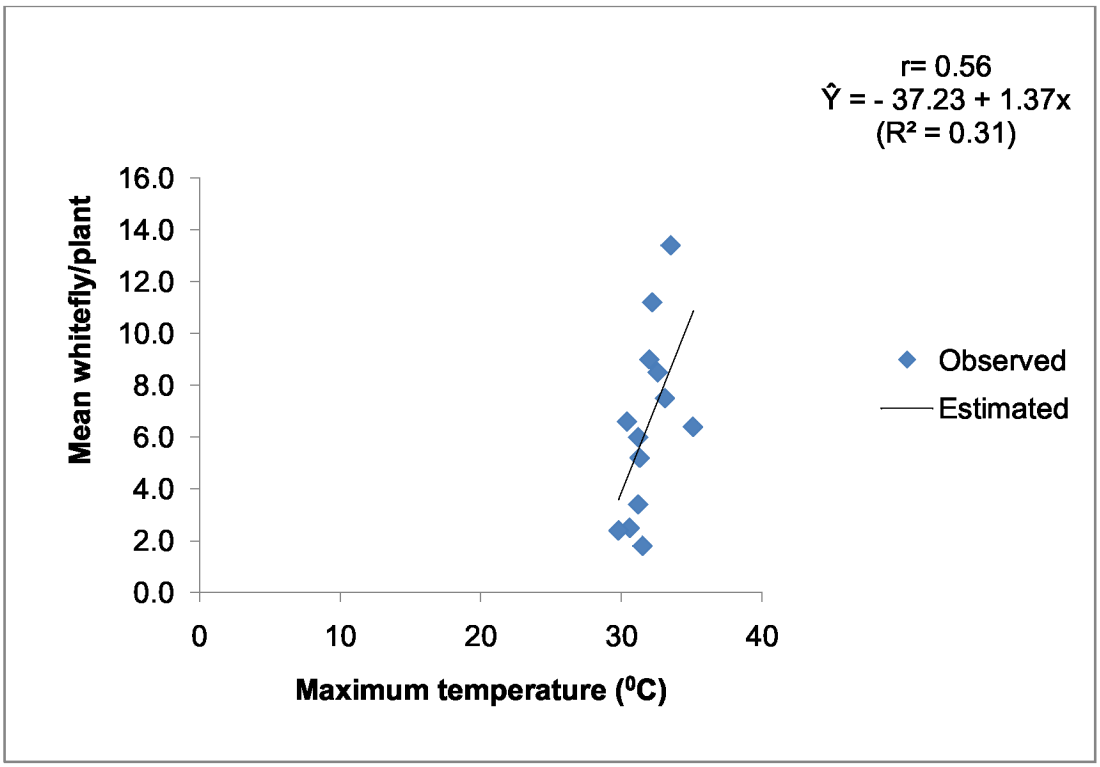

Fig. 15: Regression of whitefly infesting *kharif* soybean on maximum temperature (2015-16)

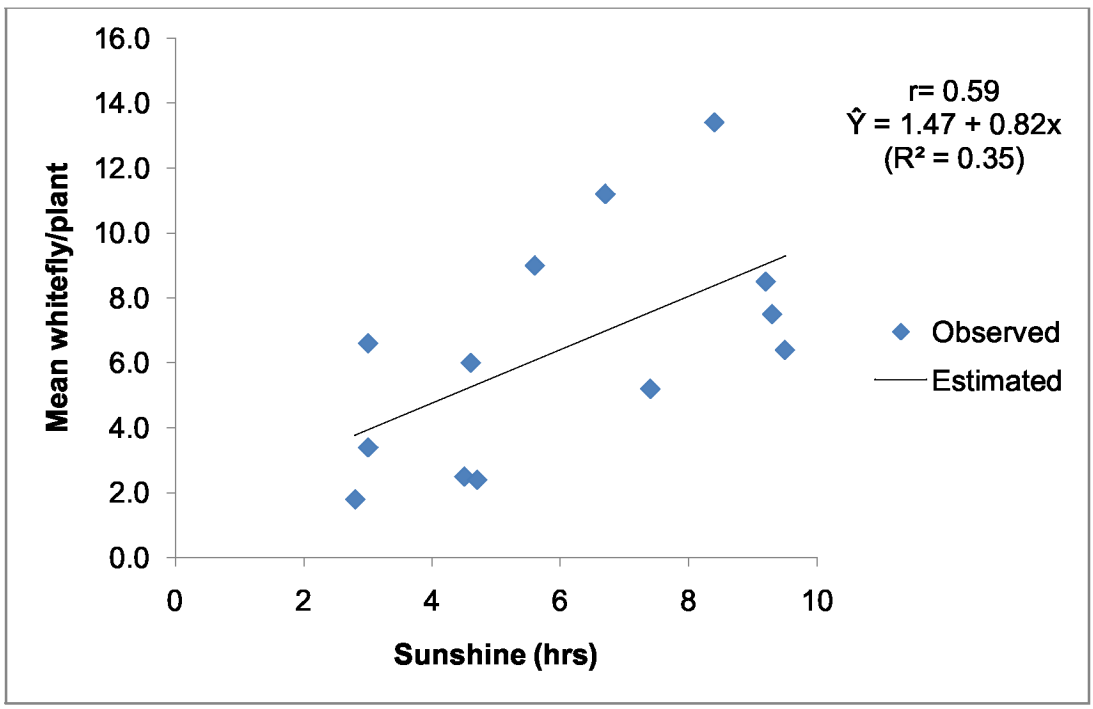

Fig. 16: Regression of whitefly infesting *kharif* soybean on sunshine (2015-16)

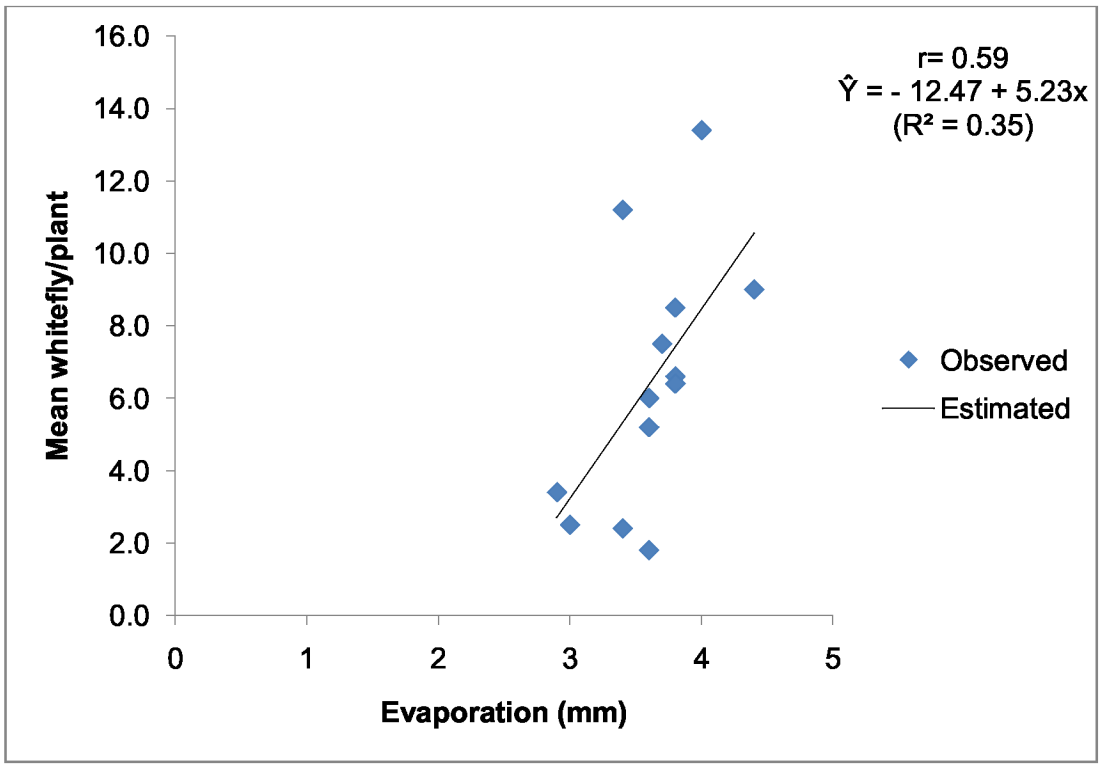

Fig. 17: Regression of whitefly infesting *kharif* soybean on evaporation (2015-16)

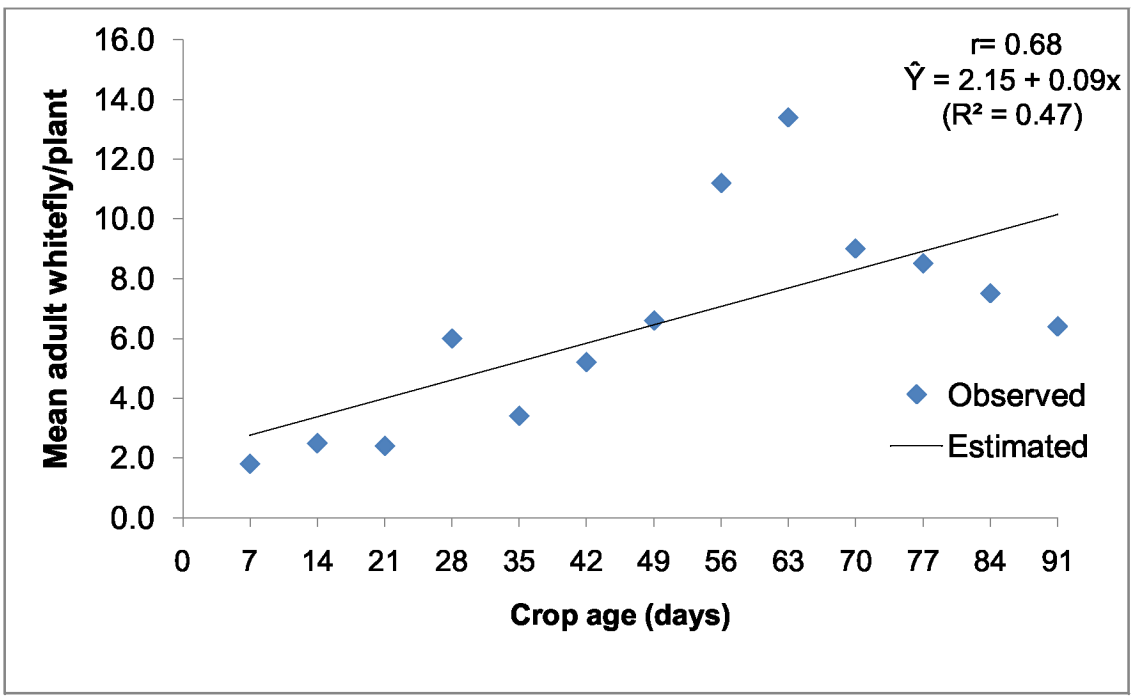

Fig. 18: Regression of whitefly infesting *kharif* soybean on crop age (2015-16)

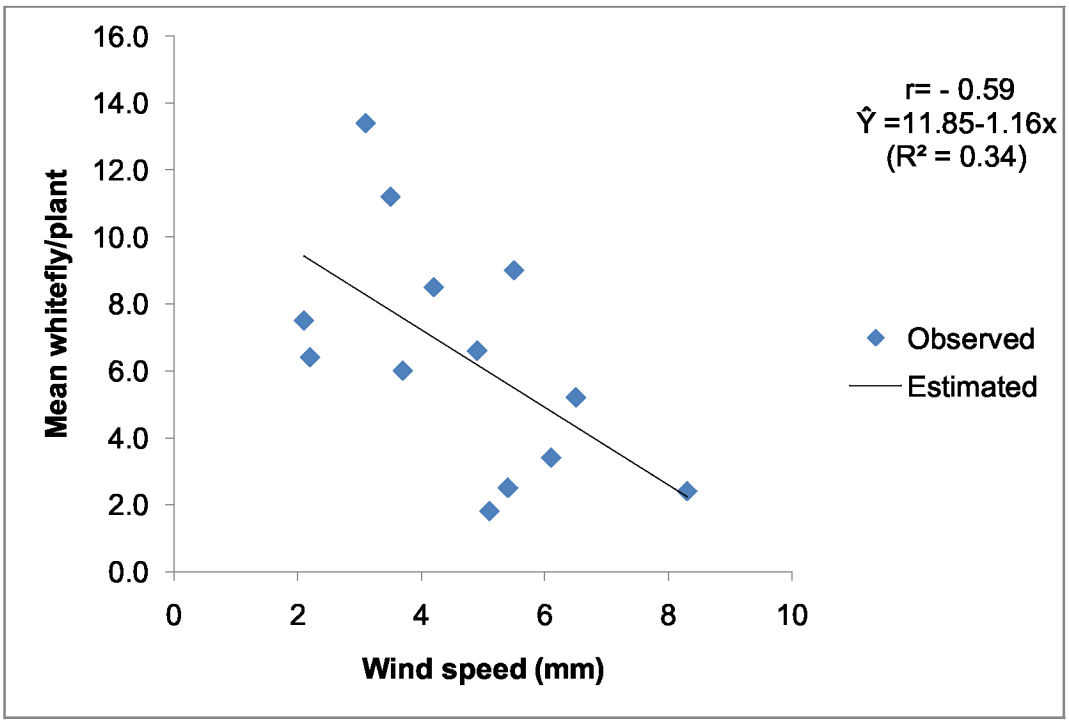

Fig. 19: Regression of whitefly infesting *kharif* soybean on wind speed (2015-16)

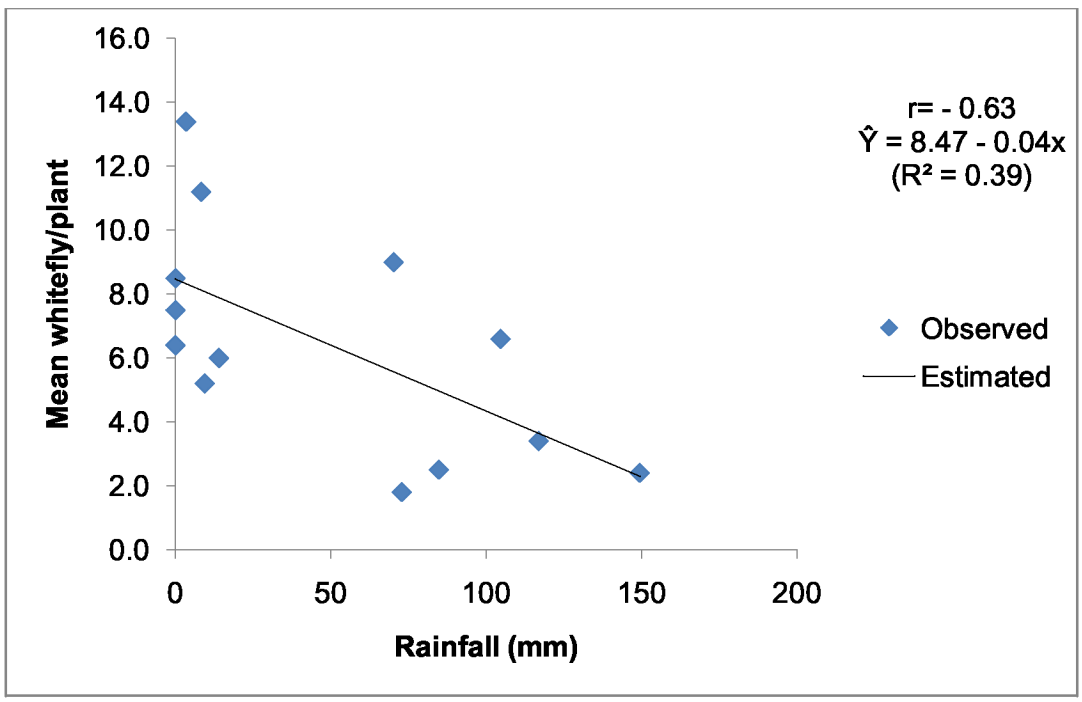

Fig. 20: Regression of whitefly infesting *kharif* soybean on rainfall (2015-16)

Path coefficient analysis:

Path coefficient analysis revealed that the Min T had the highest positive direct effect (2.1399) on whitefly population followed by SS (1.9591), Even VP (1.0906), RF (1.0328), Even RH (0.4319), Morn RH (0.3998), Evap (0.3376) and Max T (0.0474), respectively. However, Morn VP had highest negative direct effect (-2.0868) followed by WS (-1.3277), respectively (Table 14).

Min T had the highest positive indirect effect on whitefly population through Even VP (1.0423) followed by RF (0.4901), Even RH (0.3860) and Morn RH (0.1491), respectively, while it had highest negative indirect effect via Morn VP (-1.9886) followed by SS (-1.4404), WS (-0.8193), Evap (-0.1001) and Max T (-0.0351), respectively.

SS had maximum positive indirect effect on whitefly population through Morn VP (1.5530) followed by WS (0.7890), Evap (0.1371) and Max T (0.0374), respectively, while it had highest negative indirect effect via Min T (-1.5732) followed by Even VP (-0.8770), RF (-0.8213), Even RH (-0.3929) and Morn RH (-0.2204), respectively.

Morn VP had maximum positive indirect effect on whitefly population through Min T (2.0391) followed by Even VP (1.0658), RF (0.4666), Even RH (0.3831) and Morn RH (0.2363), respectively, whereas it had highest and negative indirect effect via SS (-1.4580) followed by WS (-0.6731), Evap (-0.0490) and Max T (-0.0315), respectively.

Higher R^2 (0.614) value and low residual effect (0.1237) obtained from multiple regression with significant independent factors (Table 7) and path analysis (Table 14), respectively indicated that the weather parameters selected for the study were appropriate and were responsible for almost 78% variation in the whitefly population.

.3.1.1.3.b. Second year (2016-17)

First appearance of whitefly was observed on soybean on 7 DOC [8th July, 2016 *i.e.* during 27th SW (02/07/2016 to 08/07/2016)]. The data are presented in Table 5, Appendix-II and illustrated in Fig. 14. It is evident from Fig. 14 that the whitefly population appeared on 7 DOC (27th SW) and was

available for 85 days *i.e.* 92 DOC (39th SW, 24/09/2016 to 30/09/2016). Mean population over the season was 6.03 adult whiteflies/plant with SE ±0.27.

Whitefly population attained its first peak (10.50 adult whiteflies/plant) on 28 DOC *i.e.* 30th SW (23/07/2016 to 29/07/2016), when Max T and Min T was 31.70 and 24.00^{0}C, respectively, whereas Morn RH and Even RH were 91.00 and 67.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 4.50 km/hr, 4.70 hrs, 23.20 mm, 22.50 mm and 3.70 mm, respectively. There was 61.80 mm RF received during this week.

Second peak (14.80 adult whiteflies/plant) was observed on 63 DOC *i.e.* 35th SW (27/08/2016 to 02/08/2016), when Max T and Min T was 32.20 and 23.70^{0}C, respectively, whereas Morn RH and Even RH were 90.00 and 70.00%, respectively. Further, WS, SS, Morn VP, Even VP and Evap were 4.30 km/hr, 6.10 hrs, 22.30 mm, 23.30 mm and 3.80 mm, respectively. There was 35.20 mm RF received during this week.

Correlation studies:

Correlation studies revealed that the Max T, SS and Evap exhibited positive association (r= 0.31, 0.42 and 0.43, respectively) with whitefly population, but statistically found to be non-significant (Table 6).

However, Morn RH showed significant negative association (r= -0.73) with whitefly population (Table 6).

The regression equation being:

$\hat{Y}$= 153.99 - 1.62x (R^2 = 0.54)

The above equation express that with every unit increase in Morn RH, there was a decrease of 1.62 adult whitefly population/plant (Fig. 21).

Further, crop age showed positive correlation (r= 0.15) with whitefly population, but statistically found to be non-significant (Table 6). While, Min T, Even RH, WS, Morn VP, Even VP and RF showed negative correlation (r= -0.18, -0.49, -0.29, -0.23, -0.28 and -0.21, respectively) with whitefly population, but statistically found to be non-significant (Table 6).

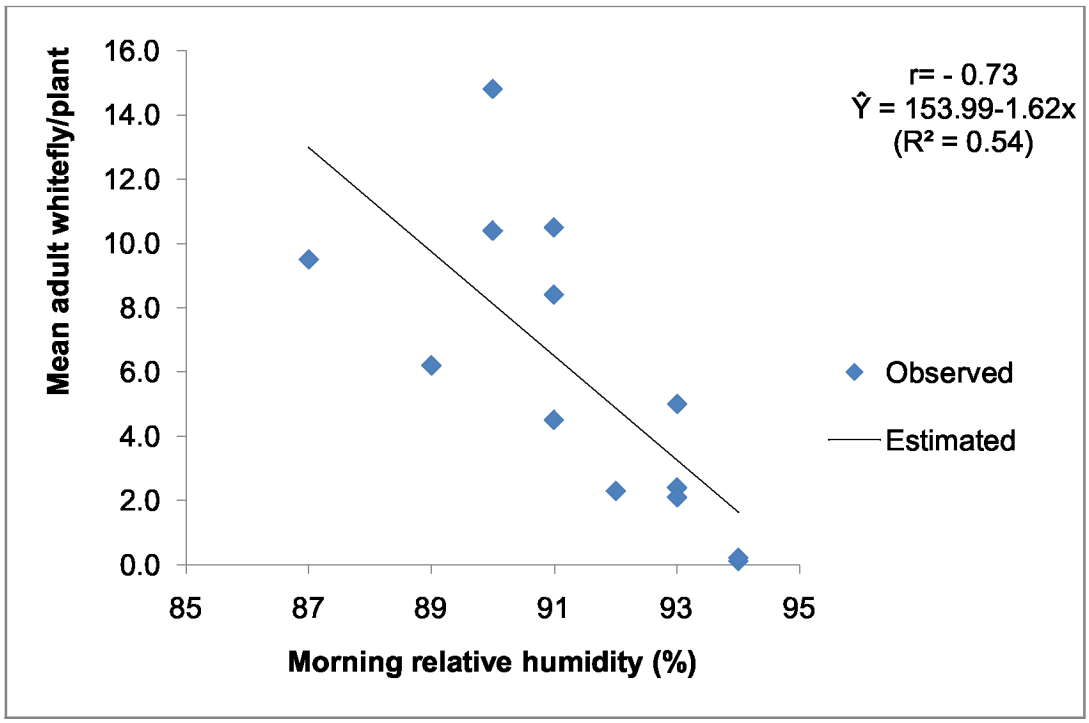

Fig. 21: Regression of whitefly infesting *kharif* soybean on morning relative humidity (2016-17)

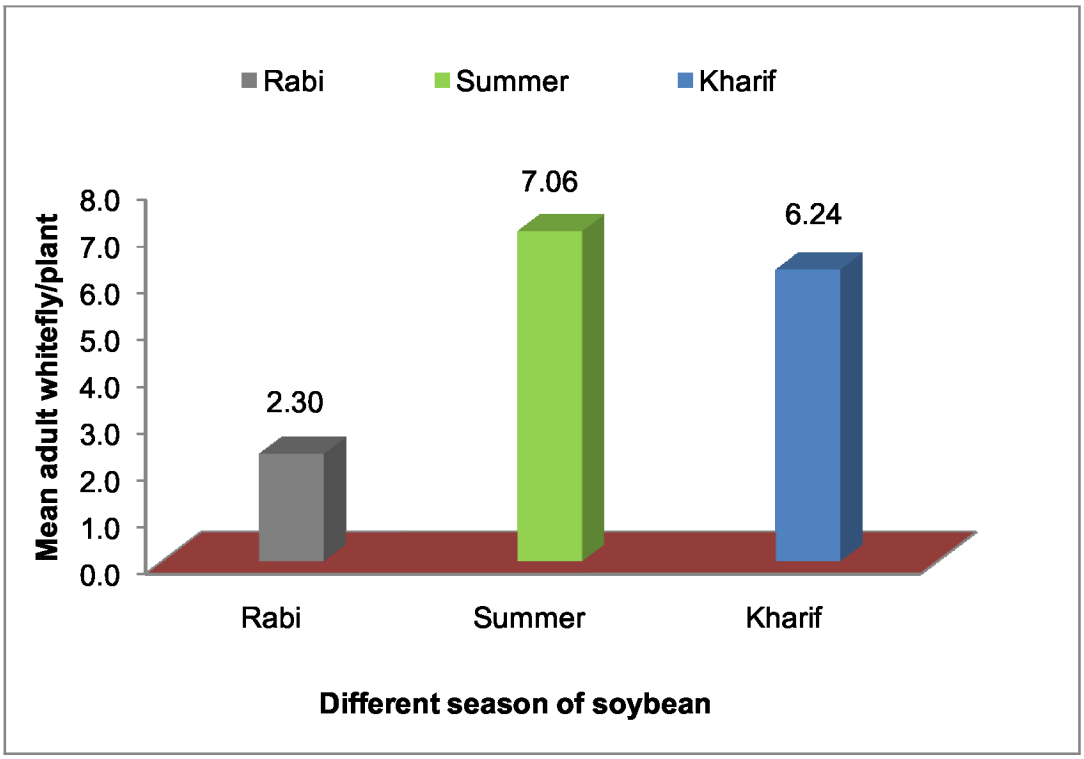

Fig. 22: Influence of sowing season of soybean on whitefly incidence (Pooled)

Table 14: Direct and indirect effect of abiotic components on adult whitefly population infesting *kharif* soybean (2015-16)

Weather factors	Max. temp.(°C)	Min. temp.(°C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm)	Evaporation (mm)	Rainfall (mm)	" r "
Max. temp.(°C)	**0.0474**	-1.5837	-0.1188	-0.3778	1.0708	1.5452	1.3880	-0.7859	0.1473	-0.7717	0.56*
Min. temp.(°C)	-0.0351	**2.1399**	0.1491	0.3860	-0.8193	-1.4404	-1.9886	1.0423	-0.1001	0.4901	-0.18
Morning RH (%)	-0.0141	0.7980	**0.3998**	0.2386	-0.2840	-1.0799	-1.2335	0.5996	0.0770	0.4936	-0.004
Evening RH (%)	-0.0414	1.9128	0.2209	**0.4319**	-0.9668	-1.7822	-1.8514	1.0227	-0.1065	0.7405	-0.42
Wind speed (km/hr)	-0.0382	1.3205	0.0855	0.3145	**-1.3277**	-1.1643	-1.0580	0.5871	-0.1086	0.8038	-0.59*
Sunshine (hrs)	0.0374	-1.5732	-0.2204	-0.3929	0.7890	**1.9591**	1.5530	-0.8770	0.1371	-0.8213	0.59*
Morning VP (mm)	-0.0315	2.0391	0.2363	0.3831	-0.6731	-1.4580	**-2.0868**	1.0658	-0.0490	0.4666	-0.11
Evening VP (mm)	-0.0341	2.0451	0.2198	0.4050	-0.7147	-1.5753	-2.0393	**1.0906**	-0.0692	0.4952	-0.18
Evaporation (mm)	0.0207	-0.6343	0.0912	-0.1362	0.4270	0.7956	0.3026	-0.2235	**0.3376**	-0.3933	0.59*
Rainfall (mm)	-0.0354	1.0154	0.1911	0.3096	-1.0333	-1.5579	-0.9428	0.5230	-0.1286	**1.0328**	-0.63*

Residual effect =0.1237

*= Significant at 5%, "r" = Correlation coefficients of adult whitefly with weather factors, Diagonal values (bold) indicated direct effects.

Table 15: Direct and indirect effect of abiotic components on adult whitefly population infesting *kharif* soybean (2016-17)

Weather factors	Max. temp.(°C)	Min. temp.(°C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm)	Evaporation (mm)	Rainfall (mm)	" r "
Max. temp.(°C)	**-1.3134**	2.8426	0.4880	0.3199	1.7181	0.1077	-1.9341	0.0054	0.5293	-2.4505	0.31
Min. temp.(°C)	-0.7451	**5.0107**	-0.3238	0.0957	0.6504	-0.0018	-2.9392	0.0189	0.4058	-2.3538	-0.18
Morning RH (%)	0.4602	1.1650	**-1.3927**	-0.2986	-0.4284	-0.0566	-1.4756	0.0370	-0.3822	1.6371	-0.73*
Evening RH (%)	1.0445	-1.1921	-1.0336	**-0.4023**	-1.0319	-0.1052	0.3036	0.0237	-0.5290	2.4354	-0.49
Wind speed (km/hr)	0.8264	-1.1936	-0.2185	-0.1520	**-2.7307**	-0.0917	1.1353	-0.0020	-0.2873	2.4227	-0.29
Sunshine (hrs)	-0.7911	-0.0506	0.4408	0.2367	1.4003	**0.1789**	0.0291	-0.0069	0.2277	-1.2444	0.42
Morning VP (mm)	-0.7413	4.2977	-0.5997	0.0356	0.9047	-0.0015	**-3.4268**	0.0366	0.2401	-0.9706	-0.23
Evening VP (mm)	-0.1274	1.7001	-0.9263	-0.1712	0.0991	-0.0221	-2.2531	**0.0557**	-0.1628	1.5326	-0.28
Evaporation (mm)	-0.9885	2.8912	0.7568	0.3026	1.1155	0.0579	-1.1699	-0.0129	**0.7033**	-3.2251	0.43
Rainfall (mm)	0.7886	-2.8897	-0.5586	-0.2401	-1.6209	-0.0545	0.8149	0.0209	-0.5558	**4.0814**	-0.21

Residual effect =0.2156

*= Significant at 5%, "r" = Correlation coefficients of adult whitefly with weather factors, Diagonal values (bold) indicated direct effects.

Table 16: Direct and indirect effect of abiotic components and crop age on adult whitefly population infesting *kharif* soybean (Pooled)

Weather factors	Max. temp.(°C)	Min. temp.(°C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm)	Evaporation (mm)	Rainfall (mm)	Crop age	" r "
Max. temp.(°C)	**0.3333**	-1.3813	-0.1783	0.2636	0.5624	0.2741	1.1115	-1.1367	0.1803	0.0841	0.2764	0.39
Min. temp.(°C)	-0.1657	**2.7788**	0.0667	-0.2002	-0.4636	-0.1935	-3.0542	1.7864	-0.0398	-0.0547	-0.3868	0.07
Morning RH (%)	-0.1373	0.4279	**0.4329**	-0.1850	-0.1585	-0.1626	-1.1304	0.8354	-0.0703	-0.0513	-0.1706	-0.37
Evening RH (%)	-0.2910	1.8426	0.2652	**-0.3019**	-0.5066	-0.3015	-2.0483	1.6218	-0.1740	-0.0930	-0.3499	-0.34
Wind speed (km/hr)	-0.2618	1.7993	0.0958	-0.2136	**-0.7160**	-0.2454	-1.5033	1.0989	-0.0769	-0.0761	-0.3313	-0.43
Sunshine (hrs)	0.2740	-1.6123	-0.2111	0.2729	0.5268	**0.3335**	1.7829	-1.4035	0.1365	0.0875	0.3317	0.52
Morning VP (mm)	-0.1137	2.6037	0.1501	-0.1897	-0.3302	-0.1824	**-3.2595**	1.8264	-0.0199	-0.0485	-0.3724	0.06
Evening VP (mm)	-0.1923	2.5193	0.1835	-0.2485	-0.3993	-0.2376	-3.0212	**1.9704**	-0.0964	-0.0771	-0.3730	0.03
Evaporation (mm)	0.1815	-0.3343	-0.0920	0.1587	0.1664	0.1375	0.1956	-0.5740	**0.3310**	0.0842	0.1975	0.45
Rainfall (mm)	-0.2354	1.2777	0.1866	-0.2361	-0.4577	-0.2454	-1.3273	1.2760	-0.2341	**-0.1190**	-0.3201	-0.43
Crop stage (days)	0.1977	-2.3067	-0.1584	0.2267	0.5090	0.2374	2.6047	-1.5771	0.1403	0.0817	**0.4660**	0.42

Residual effect =0.0316

*= Significant at 5%, "r" = Correlation coefficients of adult whitefly with weather factors, Diagonal values (bold) indicated direct effects.

Path coefficient analysis:

Path coefficient analysis revealed that Min T had highest positive direct effect (5.0107) on whitefly population followed by RF (4.0814), Evap (0.7033), SS (0.1789) and Even VP (0.0557), respectively. However, Morn VP had highest negative direct effect (-3.4268) followed by WS (-2.7307), Morn RH (-1.3927), Max T (-1.3134) and Even RH (-0.4023), respectively (Table 15).

Min T had maximum positive indirect effect on whitefly population through WS (0.6504) followed by Evap (0.4058), Even RH (0.0957) and Even VP (0.0189), respectively, while it had highest negative indirect effect via Morn VP (-2.9392) followed by RF (-2.3538), Max T (-0.7451), Morn RH (-0.3238) and SS (-0.0018), respectively.

RF had the highest positive indirect effect on whitefly population via Morn VP (0.8149) followed by Max T (0.7886) and Even VP (0.0209), respectively. Whereas, it had exerted maximum negative indirect effect through Min T (-2.8897) followed by WS (-1.6209), Morn RH (-0.5586), Evap (-0.5558), minimum RH (-0.2401) and SS (-0.0545), respectively.

Evap had maximum positive indirect effect on whitefly population through Min T (2.8912) followed by WS (1.1155), Morn RH (0.7568), Even RH (0.3026) and SS (0.0579), respectively, while it had highest negative indirect effect via RF (-3.2251) followed by Morn VP (-1.1699), Max T (-0.9885) and Even VP (-0.0129), respectively.

Morn VP had the highest positive indirect effect through Min T (4.2977) on whitefly population followed by WS (0.9047), Evap (0.2401), Even VP (0.0366) and Even RH (0.0356), respectively, whereas it had highest indirect negative effect via RF (-0.9706) followed by Max T (-0.7413), Morn RH (-0.5997) and SS (-0.0015), respectively.

Higher R^2 (0.540) value and low residual effect (0.2156) obtained from multiple regression with significant independent factors (Table 7) and path analysis (Table 15), respectively indicated that the weather parameters selected for the study were appropriate and were responsible for almost 54% variation in the whitefly population.

3.1.1.3.c. Pooled data

During first and second year of study, the first appearance of whitefly on soybean was observed on 7 DOC *i.e.* 29th SW (16/07/2015 to 22/07/2015)

and 27th SW (02/07/2016 to 08/07/2016), respectively (Table 5 and Fig. 14). The mean population of both the years were found to be non-significant. However, mean population during *kharif* season was 6.24 adult whiteflies/plant with SE± 0.20.

Whitefly population attained its first peak (8.25 adult whiteflies/plant) on 28 DOC, while second peak (14.10 adult whiteflies/plant) was recorded on 63 DOC.

Correlation studies:

Correlation studies revealed that the Max T, Min T, SS, Morn VP, Even VP, Evap and crop age showed positive correlation (r= 0.39, 0.07, 0.52, 0.06, 0.03, 0.45 and 0.42) with whitefly population, but statistically found to be non-significant (Table 6).

While Morn RH, Even RH, WS and RF exhibited negative association (r= -0.37, -0.34, -0.43, -0.43, respectively) with whitefly population, but statistically found to be non-significant (Table 6).

Path coefficient analysis:

Path coefficient analysis revealed that Min T had highest positive direct effect (2.7788) on whitefly population followed by Even VP (1.9704), crop age (0.4660), Morn VP (0.4329), SS (0.3335), Min T (0.3333) and Evap (0.3310), respectively. However, Morn VP had highest negative direct effect (-3.2595) followed by WS (-0.7160), Even RH (-0.3019) and RF (-0.1190), respectively (Table 16).

Min T had the highest positive indirect effect on whitefly population through Even VP (1.7864) followed by Morn RH (0.0667), whereas it had highest negative indirect effect via Morn VP (-3.0542) followed by WS (-0.4636), crop age (-0.3868), Even RH (-0.2002), SS (-0.1935), Max T (-0.1657), RF (-0.0547) and Evap (-0.0398), respectively.

Even VP had the highest indirect positive effect on whitefly population through Min T (2.5193) followed by Morn RH (0.1835), while it had maximum negative indirect effect via Morn VP (-3.0212) followed by WS (-0.3993), crop age (-0.3730), Even RH (-0.2485), SS (-0.2376), Max T(-0.1923), Evap (-0.0964) and RF (-0.0771), respectively.

Morn VP had the highest negative direct effect on whitefly population which had indirect positive effect through Min T (2.6037) followed by Even VP

(1.8264) and Morn RH (0.1501), respectively, while it had maximum negative indirect effect via crop age (-0.3724) followed by WS (-0.3302), Even RH (-0.1897), SS (-0.1824), Max T(-0.1137) RF (0-0.0199) and Evap (-0.0199), respectively.

Low residual effect (0.0316) obtained from path analysis indicated that the factors included in the study played a major role in influencing the whitefly population which was not included in this study.

Influence of sowing season of soybean on whitefly incidence

Paired 't' test was applied to study the influence of sowing season of soybean on whitefly population. Mean whitefly population was found to be significantly lowest on soybean crop planted during *rabi* followed by *kharif* and summer season (2.30 and 6.24 and 7.06 adult whiteflies / plant) (Table 5 and Fig. 22). However, the mean whitefly population on summer and *kharif* planted crops were at par with each other.

3.1.2. Yellow mosaic disease:

3.1.2.1 Post *Kharif* / *Rabi* season

3.1.2.1.a. First year (2014-15)

First incidence of yellow mosaic disease (YMD) on soybean was observed on 56 days old crop (DOC) [26th January, 2015 *i.e.* 4th SW (22/01/2015 to 28/01/2015)]. The YMD incidence was recorded weekly as percent disease incidence (PDI) and the data are presented in Table 17, Appendix-I and Fig.1. It is evident from the Fig. 1 that the first incidence of YMD occurred on 56 DOC (4th SW) and during that period Max T and Min T was 21.00 and 12.10^{0}C, respectively, whereas Morn RH and Even RH were 89.00 and 75.00%, respectively. Further WS, SS, Morn VP, Even VP, Evap and RF were 3.30 km/hr, 3.70 hrs, 11.10 mm, 12.60 mm, 0.90 mm and 10.20 mm, respectively. The whitefly population recorded during this week was 0.90 adult whitefly/ plant.

Table 17: Influence of crop age on yellow mosaic disease incidence on soybean planted in different seasons

Crop age (days)	Percent disease incidence (PDI %) on soybean planted in different seasons								
	Rabi			Summer			*Kharif*		
	2014-15	2015-16	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	2.22	0.00	2.22	1.67	0.00	1.67
28	0.00	0.00	0.00	3.33	1.11	2.22	10.00	1.11	5.56
35	0.00	0.00	0.00	8.33	3.33	5.83	17.78	2.78	10.28
42	0.00	0.56	0.56	10.56	7.22	8.89	53.33	3.89	28.61
49	0.00	0.56	0.56	23.89	8.33	16.11	81.11	6.11	43.61
56	1.11	2.22	1.67	54.44	11.67	33.06	100.00	11.67	55.84
63	2.78	3.89	3.34	56.11	19.44	37.78	100.00	19.44	59.72
70	5.00	5.56	5.28	61.11	42.22	51.67	100.00	22.22	61.11
77	8.89	10.00	9.45	#	56.67	56.67	100.00	43.89	71.95
84	10.00	11.11	10.56	-	60.00	60.00	100.00	58.89	79.45
91	13.89	14.44	14.17	-	67.78	67.78	100.00	62.22	81.11
98	16.11	15.00	15.56	-	#	-	#	#	-
105	18.89	15.56	17.23	-	-	-	-	-	-
112	23.33	#	23.33	-	-	-	-	-	-
119	33.89	-	33.89	-	-	-	-	-	-
	#	-	-	-	-	-	-	-	-

Signifies that the crop has matured

Table 18: Correlation (r) and regression coefficient (byx) of abiotic factors, whitefly population and crop age on yellow mosaic disease of soybean planted in Rabi season

Weather factors	Same week						P_1W						P_2W					
	2014-15		2015-16		Pooled		2014-15		2015-16		Pooled		2014-15		2015-16		Pooled	
	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx
Max. temp.(°C)	0.76**	1.91	0.92**	1.12	0.88**	2.31	0.85**	2.44	0.93**	1.43	0.85**	2.44	0.72*	2.31	0.90**	1.46	0.92**	2.54
Min. temp.(°C)	0.79**	1.68	0.87**	1.17	0.59*	0.73	0.74*	2.54	0.89**	1.51	0.57*	0.57	0.82**	2.46	0.88**	1.33	0.92**	1.00
Morning RH (%)	-0.83**	-2.58	-0.83**	-0.45	0.15 NS	-	-0.81**	-2.76	-0.77**	-0.51	0.29 NS	-	-0.48 NS	-	-0.73*	-0.56	0.70*	0.31
Evening RH (%)	-0.30 NS	-	-0.63*	-0.29	-0.19 NS	-	-0.43 NS	-	-0.62 NS	-	-0.08 NS	-	0.03 NS	-	-0.35 NS	-	0.51 NS	-
Wind speed (km/hr)	0.17 NS	-	0.37 NS	-	0.34 NS	-	-0.19 NS	-	0.01 NS	-	0.28 NS	-	0.27 NS	-	0.37 NS	-	0.82**	5.47
Sunshine (hrs)	0.26 NS	-	0.61*	2.85	0.44 NS	-	0.31 NS	-	0.61 NS	-	0.56 NS	-	-0.03 NS	-	0.33 NS	-	0.78**	2.11
Morning VP (mm)	0.76**	3.51	0.74**	1.93	0.55*	1.04	0.68*	3.92	0.76*	2.30	0.53 NS	-	0.81**	4.18	0.79**	2.01	0.90**	1.51
Evening VP (mm)	0.43 NS	-	-0.25 NS		0.34 NS	-	0.24 NS	-	-0.27 NS	-	0.36 NS	-	0.69*	3.32	0.07 NS	-	0.80**	1.89
Evaporation (mm)	0.78**	7.35	0.93**	3.15	0.63**	2.53	0.69*	7.35	0.90**	4.03	0.61*	2.26	0.42 NS		0.88**	5.06	0.90**	3.24
Rainfall (mm)	0.06 NS	-	0.07 NS	-	0.07 NS	-	0.07 NS	-	0.28 NS	-	0.08 NS	-	0.37 NS	-	0.39 NS	-	0.37 NS	-
Whitefly population (nos./plant)	0.70**	4.83	0.57*	2.39	0.63**	4.66	0.78**	5.89	0.47 NS	-	0.81**	8.48	0.76*	5.73	0.60 NS	-	0.68*	6.40
Crop age (days)	0.89**	0.26	0.93**	0.18	0.90**	0.25	0.97**	0.46	0.98**	3.45	0.95**	0.38	0.97**	0.46	0.98**	0.28	0.95**	0.38

NS= Non-significant, *= Significant at 5%, **= Significant at 1%, P_1W= Preceding one week of infection, P_2W= Preceding two weeks of infection

Thereafter, there was a gradual increase in the disease infection and it was maximum (33.89%) on 119 DOC (13^{th} SW, 26/03/2015 to 01/04/2015), when Max T and Min T was 35.10 and 17.40^0C, respectively, whereas Morn RH and Even RH were 78.00 and 23.00%, respectively. Further WS, SS, Morn VP, Even VP and Evap were 3.30 km/hr, 8.50 hrs, 13.20 mm, 9.30 mm and 4.90 mm, respectively with no RF, while whitefly population was 2.50 adult whiteflies/plant.

Correlation studies:

Same week (SW):

Correlation studies of weather parameters, vector population and crop age with disease incidence of the same week revealed that Max T, Min T, Morn VP, Evap, whitefly population and crop age showed significant positive association (r= 0.76, 0.79, 0.76, 0.78, 0.70 and 0.89, respectively) with disease incidence (Table 18).

The regression equations being:

$\hat{Y}$ = - 42.07+1.91x (R^2 = 0.58)

$\hat{Y}$ = -10.66+1.68x (R^2 = 0.53)

$\hat{Y}$= - 25.95+3.51x (R^2 = 0.58)

$\hat{Y}$= - 9.59+7.35x (R^2 = 0.60)

$\hat{Y}$= - 1.91+4.83x (R^2 = 0.49)

$\hat{Y}$= - 8.35+0.26x (R^2 = 0.80)

The above equations expresse that with every unit increase in Max T, Min T, Morn VP, Evap, vector population and crop age there was an increase of 1.91, 1.68, 3.51, 7.35, 4.83 and 0.26% YMD incidence.

Correlation studies further revealed that WS, SS, Even VP and RF exhibited positive correlation (r= 0.17, 0.26, 0.43 and 0.06, respectively) with disease incidence, but statistically non-significant (Table 18).

Further, Morn RH showed significant negative correlation (r= -0.83) with disease incidence (Table 18).

The regression equation being:

$\hat{Y}$ = 230.70 -2.58x (R^2 = 0.71)

The above equation express that with every unit increase in Morn RH there was a decrease of 2.58% YMD incidence (Fig. 23).

While Even RH exhibited negative correlation (r= -0.30) with disease incidence, but statistically non-significant (Table 18).

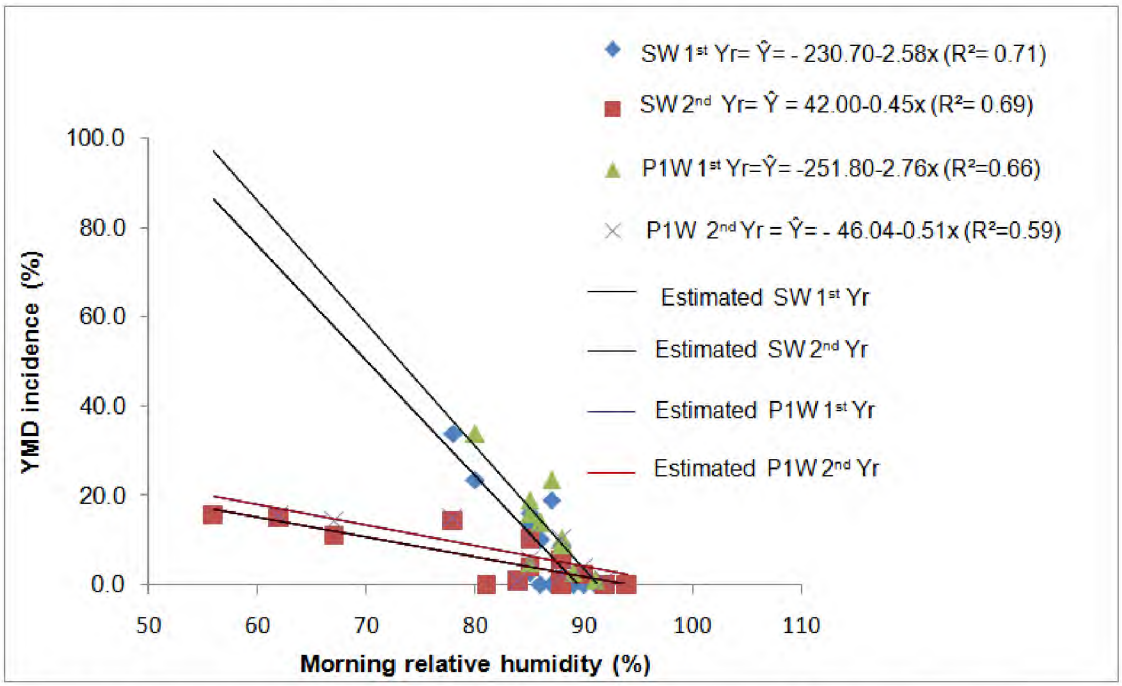

Fig. 23: Regression of YMD incidence on morning relative humidity during *rabi* soybean

Preceding one week (P_1W):

Correlation studies between independent factors (*viz.* weather parameters, vector population and crop age) with preceding one week of YMD infection, revealed that Max T, Min T, Morn VP, Evap and whitefly population exhibited significant positive association (r= 0.85, 0.74, 0.68, 0.69, 0.78 and 0.97, respectively) with disease incidence (Table 18).

The regression equations being:

$\hat{Y}$ = - 49.02+2.44x (R^2 = 0.72)

$\hat{Y}$ = - 15.60+2.54x (R^2 = 0.54)

$\hat{Y}$ = -27.03+3.92x (R^2 = 0.46)

$\hat{Y}$ = - 4.54+7.35x (R^2 = 0.47)

$\hat{Y}$ = - 3.25+5.89x (R^2 = 0.60)

$\hat{Y}$ = - 27.05+0.46x (R^2 = 0.94)

The above equations express that with every unit increase in Max T, Min T, Morn VP, Evap and whitefly population there was an increase of 2.44, 2.54, 3.92, 7.35, 5.89 and 0.46% disease incidence.

Correlation studies further revealed that SS, Even VP and RF exhibited positive correlation (r= 0.31, 0.24 and 0.07, respectively) with disease incidence, but statistically found to be non-significant (Table 18).

Further, Morn RH showed significant negative correlation (r= -0.81) with disease incidence (Table 18).

The regression equation being:

$\hat{Y}$ = 251.80- 2.76x (R^2 = 0.66)

The above equation express that with every unit increase in Morn RH there was a decrease of 2.76% disease incidence (Fig.23).

While Even RH and WS exhibited negative correlation (r= -0.43 and -0.19, respectively) with disease incidence, but statistically found to be non-significant (Table 18).

Preceding two week (P_2W):

Further, correlation studies computed between independent factors (*viz.* weather parameters, vector population and crop page) preceding two week of YMD infection showed that Max T, Min T, Morn and Even VP, whitefly population and crop age exhibited significant positive association (r= 0.72, 0.82, 0.81, 0.69, 0.76 and 0.97, respectively) with disease incidence (Table 18).

The regression equations being:

$\hat{Y}$ = - 44.55+2.31x (R^2 = 0.51)

$\hat{Y}$ = - 12.59+2.46x (R^2 = 0.67)

$\hat{Y}$ = - 26.84+4.18x (R^2 = 0.66)

$\hat{Y}$ = - 21.94+3.32x (R^2 = 0.48)

$\hat{Y}$ = - 0.83+5.73x (R^2 = 0.57)

$\hat{Y}$ = - 23.82+0.46x (R^2 = 0.94)

The above equations express that with the every unit increase in Max T, Min T, Morn and Even VP and whitefly population, there was an increase of 2.31, 2.46, 4.18, 3.32, 5.73 and 0.46% YMD incidence.

Correlation studies further revealed that Even RH, WS, Evap and RF exhibited positive correlation (r= 0.03, 0.27, 0.42 and 0.37, respectively) with disease incidence, but statistically found to be non-significant (Table 18).

While Morn RH and SS exhibited negative correlation (r= -0.48 and -0.03, respectively) with disease incidence and also statistically found to be non-significant (Table 18).

Multiple regression:

R^2 obtained by computation of multiple regression equations between significant independent factors (x) of same week, preceding one and two weeks of YMD infection showed that the abiotic factors, vector population and crop age were responsible for influencing the disease incidence to the extent of 99, 98 and 99%, respectively (Table 21).

3.1.2.1.b. Second year (2015-16)

First appearance of YMD on soybean was observed on 42 days old crop (DOC) [5th February, 2016 *i.e.* 6th SW (05/02/2016 to 11/02/2016)]. The YMD incidence was recorded weekly as percent disease incidence and the data are presented in Table 17, Appendix-II and illustrated in Fig.1. It is evident from Fig.1, that the first incidence of YMD occurred on 42 DOC (6th SW) and during that period Max T and Min T was 26.40 and 8.40^{0}C, respectively, whereas Morn RH and Even RH were 84.00 and 34.00%, respectively. Further WS, SS, Morn VP, Even VP and Evap were 3.20 km/hr, 8.30 hrs, 8.10 mm, 8.90 mm and 2.80 mm, respectively. Further, there was no RF received and whitefly population recorded was 2.80 adult whiteflies/plant.

Thereafter, there was a gradual increase in the disease infection and maximum incidence (15.56%) was recorded on 105 DOC (15th SW, 09/04/2016 to 15/04/2016), when Max T and Min T was 38.90 and 19.60^{0}C, respectively, whereas Morn RH and Even RH were 56.00 and 12.00%, respectively. Further WS, SS, Morn VP, Even VP and Evap were 3.80 km/hr, 10.20 hrs, 12.20 mm, 6.50 mm and 7.70 mm, respectively, with no rainfall, while whitefly population was 2.60 adult whiteflies/plant.

Correlation studies:

Same week (SW):

Correlation studies of weather parameters, vector population and crop age with disease incidence of the same week revealed that Max T, Min T, SS,

Morn VP, Evap, vector population and crop age exhibited significant positive association (r= 0.92, 0.87, 0.61, 0.74, 0.93, 0.57 and 0.93, respectively) with disease incidence (Table 18).

The regression equations being:

$\hat{Y}$ = - 28.63+1.12x (R^2 = 0.85)

$\hat{Y}$ = -9.43+1.17x (R^2 = 0.76)

$\hat{Y}$= - 19.07+2.85x (R^2 = 0.37)

$\hat{Y}$= - 15.13+1.93x (R^2 = 0.54)

$\hat{Y}$= - 5.73+3.15x (R^2 = 0.87)

$\hat{Y}$= - 0.59+2.39x (R^2 = 0.33)

$\hat{Y}$= - 4.99+0.18x (R^2 = 0.86)

The above equations express that with every unit increase in Max T, Min T, SS, Morn VP, Evap, vector population and crop age there was an increase of 1.12, 1.17, 2.85, 1.93, 3.15, 2.39 and 0.18% YMD incidence.

Correlation studies further revealed that WS and RF exhibited positive correlation (r= 0.37 and 0.07, respectively) with disease incidence, but statistically found to be non-significant (Table 18).

However, Morn and Even RH showed significant negative correlation (r= -0.83 and -0.63, respectively) with disease incidence (Table 18).

The regression equation being:

$\hat{Y}$ = 42.00 -0.45x (R^2 = 0.69)

$\hat{Y}$ = 14.66 -0.29x (R^2 = 0.40)

The above equations express that with every unit increase in Morn and Even RH there was a decrease of 0.45 (Fig. 23) and 0.29% disease incidence.

While Even VP exhibited negative correlation (r= -0.25) with disease incidence, but statistically found to be non-significant (Table 18).

Preceding one week (P_1W):

Correlation studies between independent factors (*viz.* weather parameters, vector population and crop age) preceding one week of YMD infection, revealed that Max T, Min T, Morn VP, Evap and crop age exhibited significant positive association (r= 0.93, 0.89, 0.76, 0.90 and 0.98, respectively) with disease incidence (Table 18).

The regression equations being:

$\hat{Y}$ = - 37.23+1.43x (R^2 = 0.89)

$\hat{Y}$ = - 12.26+1.51x (R^2 = 0.79)

$\hat{Y}$ = -18.12+2.30x (R^2 = 0.58)

$\hat{Y}$ = - 7.24+4.03x (R^2 = 0.81)

$\hat{Y}$ = 39.30+3.45x (R^2 = 0.97)

The above equations express that with every unit increase in Max T, Min T, Morn VP, Evap and crop age there was an increase of 1.43, 1.51, 2.30, 4.03 and 3.45% disease incidence.

Correlation studies further revealed that WS, SS, RF and whitefly population exhibited positive correlation (r= 0.01, 0.61, 0.28 and 0.47, respectively) with disease incidence, but statistically found to be non-significant (Table 18).

Further, Morn RH showed significant negative correlation (r= -0.77) with disease incidence (Table 18).

The regression equation being:

$\hat{Y}$ = 46.04-0.51x (R^2 = 0.59)

The above equation express that with every unit increase in Morn RH there was a decrease of 0.51% disease incidence (Fig. 23).

While Even RH and Even VP exhibited negative correlation (r= -0.62 and -0.27, respectively) with disease incidence, but statistically found to be non-significant (Table 18).

Preceding two week (P_2W):

Further, correlation studies computed between independent factors (*viz.* weather parameters, vector population and crop age) preceding two week of YMD infection, revealed that Max T, Min T, Morn VP, Evap and crop age exhibited significant positive association (r= 0.90, 0.88, 0.79, 0.88 and 0.98, respectively) respectively) with disease incidence (Table 18).

The regression equations being:

$\hat{Y}$ = -35.98+1.46x (R^2 = 0.81)

$\hat{Y}$ = - 8.17+1.33x (R^2 = 0.77)

$\hat{Y}$ = - 13.43+2.01x (R^2 = 0.62)

$\hat{Y}$ = - 8.75+5.06x (R^2 = 0.78)

$\hat{Y}$ = - 8.77+0.28x (R^2 = 0.97)

The above equations express that with every unit increase in Max T, Min T, Morn VP, Evap and crop age there was an increase of 1.46, 1.33, 2.01, 5.06 and 0.28% disease incidence.

Correlation studies further revealed that WS, SS, Even VP, RF and whitefly population exhibited positive correlation (r= 0.37, 0.33, 0.07, 0.39 and 0.60, respectively) with disease incidence, but statistically found to be non-significant (Table 18).

Further, Morn RH expressed significant negative correlation (-0.73) with disease incidence (Table 18).

The regression being:

$\hat{Y}$ = 55.71-0.56x (R^2 = 0.54)

From the above equations it may be expressed that with every unit increase in Morn RH there was an decrease of 0.56% disease incidence.

While Even RH exhibited negative correlation (r= -0.35) with disease incidence, but statistically found to be non-significant (Table 18).

Multiple regression:

R^2 value obtained by computation of multiple regression equations between significant independent factors (x) of same week, prior to one and two weeks of YMD infection showed that the abiotic factors, vector population and crop age were responsible for influencing the disease incidence to the tune of 99%, 98% and 99%, respectively (Table 21).

3.1.2.1.c. Pooled data

Pooled analysis of the data showed that the first incidence of YMD was observed when the crop age was 49±7 days (Table 17 and Fig.1). During the first incidence the Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 23.7±2.7^{0}C, 10.25±1.85^{0}C, 86.5±2.5%, 54.5±20.5%, 3.25±0.05 km/hr, 6±2.3 hrs, 9.6±1.5 mm,10.75±1.85 mm, 1.85±0.95 mm, 5.1±5.1 mm and 1.85±0.95 adult whiteflies/plant, respectively.

There was a gradual increase in the disease infection and it attained maximum (24.72±9.16%) on 112±7 DOC, when Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap and vector population were

37±1.9^{0}C, 18.5±1.1^{0}C, 67±11%, 17.5±5.5%, 3.55±0.25 km/hr, 9.35±0.85 hrs, 12.7±0.5 mm, 7.9±1.4 mm, 6.3±1.4 mm and 2.55±0.05 adult whiteflies/plant, respectively.

Correlation studies:

Same week (SW):

Correlation studies of weather parameters, vector population and crop age with disease incidence of the same week revealed that Max T, Min T, Morn VP, Evap, whitefly population and crop age showed significant positive association (r= 0.88, 0.59, 0.55, 0.63, 0.63 and 0.90, respectively) with disease incidence (Table 18).

The regression equations being:

$\hat{Y}$ = - 57.70+2.31x (R^2 = 0.77)

$\hat{Y}$ = - 1.20+ 0.73x (R^2 = 0.35)

$\hat{Y}$ = - 4.17+1.04x (R^2 = 0.30)

$\hat{Y}$ = - 1.02+2.53x (R^2 = 0.39)

$\hat{Y}$ = - 2.73+4.66x (R^2 = 0.39)

$\hat{Y}$= - 7.99+0.25x (R^2 = 0.80)

The above equations express that with every unit increase in Max T, Min T, Morn VP, Evap, whitefly population and crop age there was an increase of 2.31, 0.73, 1.04, 2.53, 4.66 and 0.25% YMD incidence (Fig. 24, 25, 26, 27, 28 and 29, respectively).

Correlation studies further revealed that the Morn RH, WS, SS, Even VP and RF exhibited positive correlation (r= 0.15, 0.34, 0.44, 0.34 and 0.07, respectively) with disease incidence, but statistically found to be non-significant (Table 18).

While, Even RH showed negative correlation (r= -0.19) with disease incidence, but statistically found to be non-significant (Table 18).

Preceding one week (P_1W):

Correlation studies between independent factors (*viz.* weather parameters, vector population and crop age) preceding one week of YMD infection revealed that Max T, Min T, Evap, whitefly population and crop age

exhibited significant positive association (r= 0.85, 0.57, 0.61, 0.81 and 0.95, respectively) with disease incidence (Table 18).

The regression equations being:

$\hat{Y}$ =- 58.89+2.44x (R^2 = 0.72)

$\hat{Y}$ = 1.18+ 0.57x (R^2 = 0.32)

$\hat{Y}$ = 2.308+2.26x (R^2 = 0.37)

$\hat{Y}$ = - 13.33+ 8.48x (R^2 = 0.65)

$\hat{Y}$ =- 16.94+ 0.38x (R^2 = 0.90)

The above equations express that with every unit increase in Max T, Min T, Evap, whitefly population and crop age there was an increase of 2.44, 0.57, 2.26, 8.48 and 0.38% disease incidence (Fig. 24, 25, 27, 28 and 29, respectively).

Correlation studies further revealed that Morn RH. WS, SS, Morn and Even VP and RF exhibited positive correlation (r= 0.29, 0.28, 0.56, 0.53, 0.36 and 0.08, respectively) with disease incidence, but statistically found to be non-significant (Table 18).

While, Even RH showed negative correlation (r= -0.08) with disease incidence, but statistically found to be non-significant (Table 18).

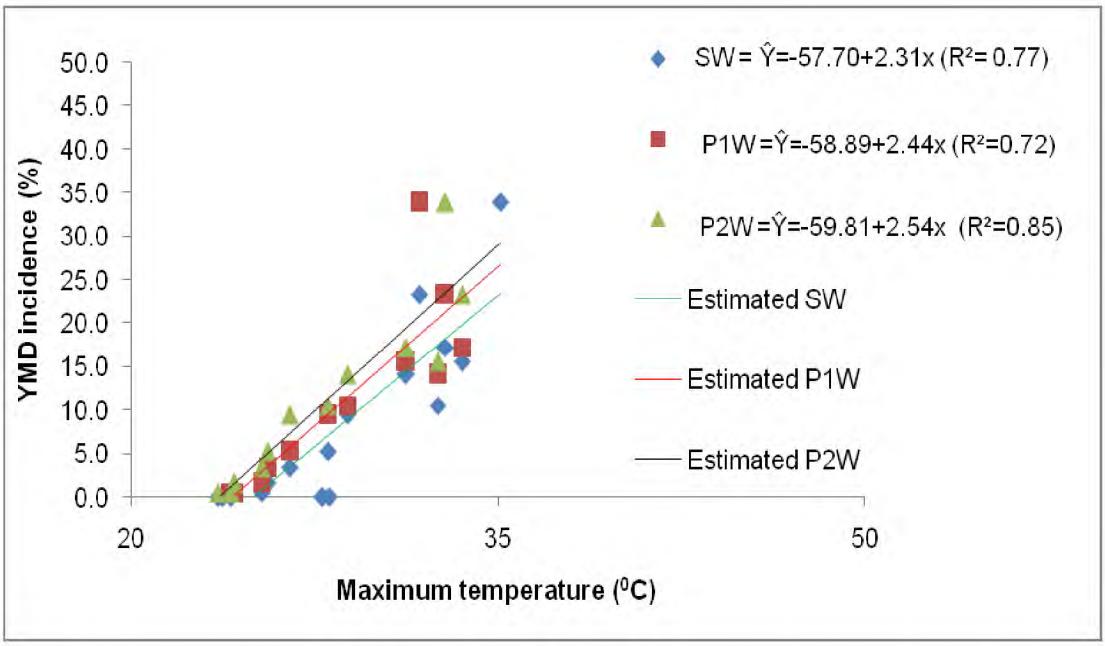

Fig. 24: Regression of YMD incidence on maximum temperature during *rabi* soybean (Pooled)

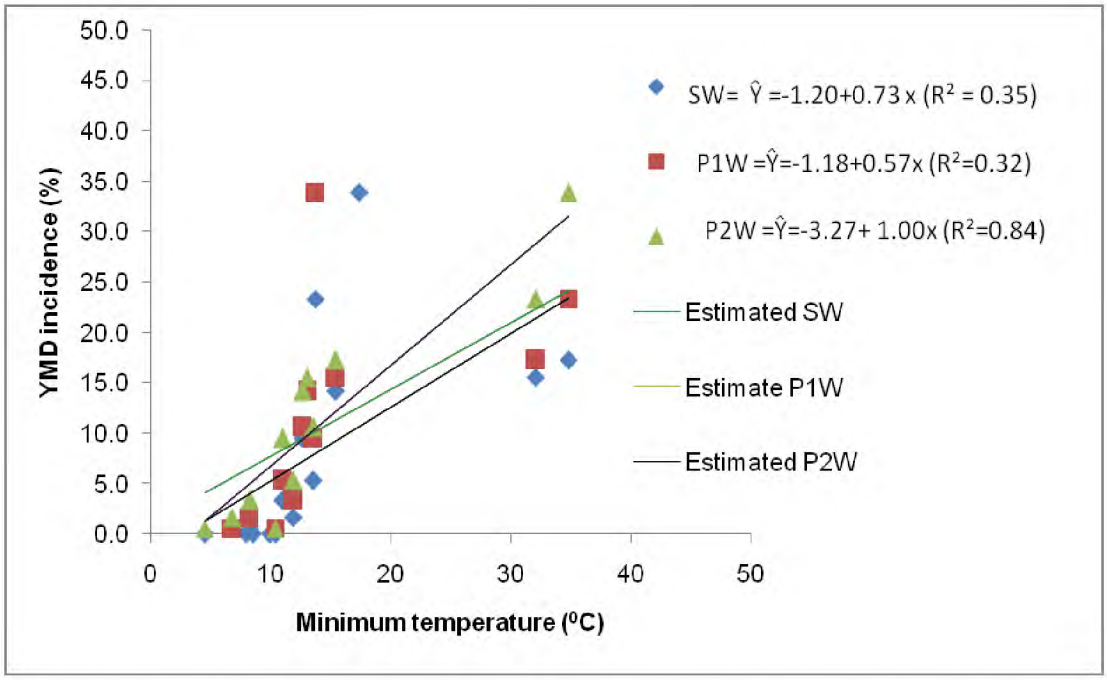

Fig. 25: Regression of YMD incidence on minimum temperature during *rabi* soybean (Pooled)

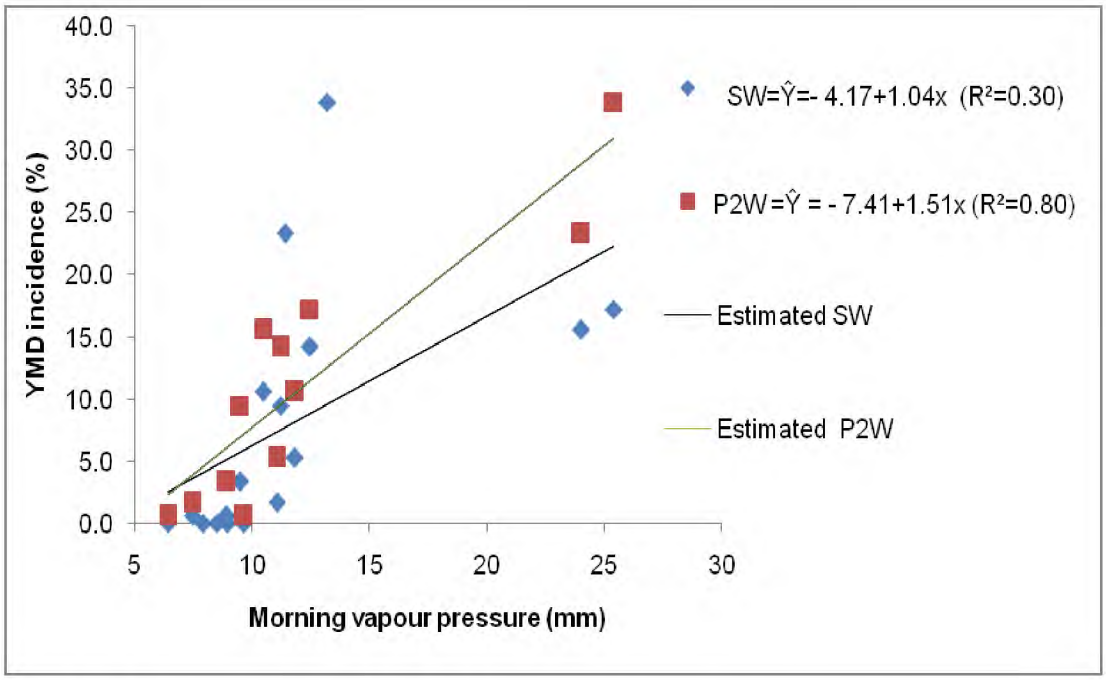

Fig. 26: Regression of YMD incidence on morning vapour pressure during *rabi* soybean (Pooled)

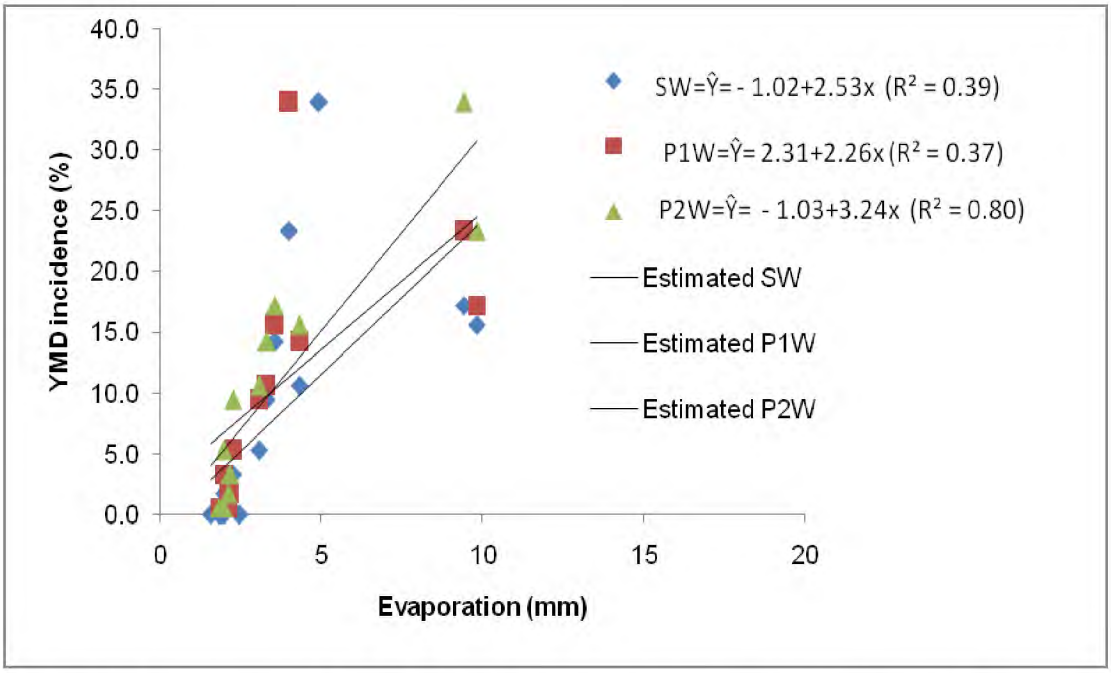

Fig. 27: Regression of YMD incidence on evaporation during *rabi* soybean (Pooled)

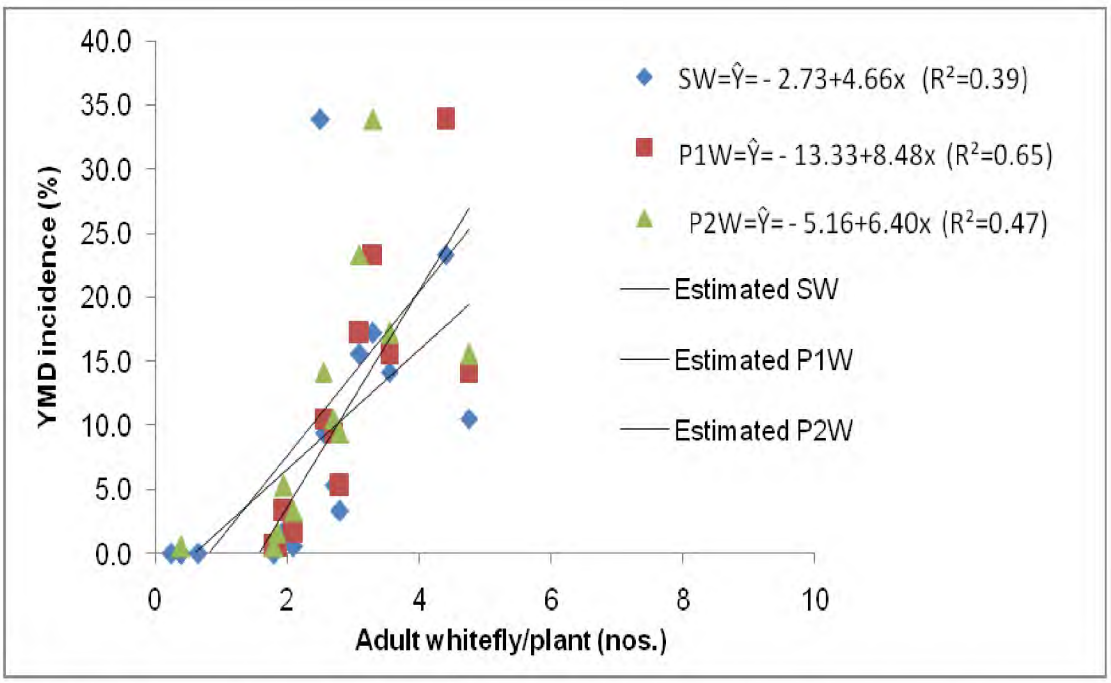

Fig. 28: Regression of YMD incidence on adult whitefly during *rabi* soybean (Pooled)

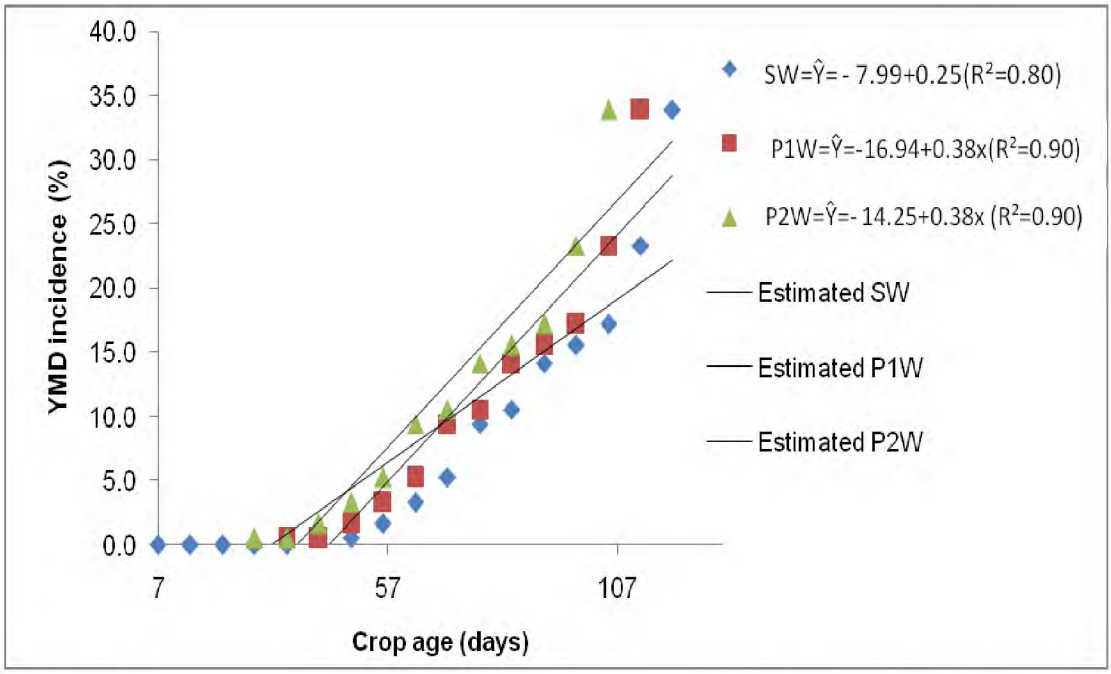

Fig. 29: Regression of YMD incidence on crop age during *rabi* soybean (Pooled)

Preceding two week (P_2W):

Further, correlation studies computed between independent factors (*viz.* weather parameters, vector population and crop page) preceding two week of YMD infection showed that Max T, Min T, Morn RH, WS, SS, Morn and Even VP, Evap, whitefly population and crop age exhibited significant positive association (r= 0.92, 0.92, 0.70, 0.82, 0.78, 0.90, 0.80, 0.90, 0.68 and 0.95, respectively) with disease incidence (Table 18).

The regression equations being:

$\hat{Y}$ = - 59.81+ 2.54x (R^2 = 0.85)

$\hat{Y}$ = - 3.27+1.00x (R^2 = 0.84)

$\hat{Y}$ = - 18.07+0.31x (R^2 = 0.48

$\hat{Y}$ = - 8.40+5.47x (R^2 = 0.67)

$\hat{Y}$ = - 9.29+2.11x (R^2 = 0.60)

$\hat{Y}$ = - 7.41+1.51x R^2 = (0.80)

$\hat{Y}$ = - 10.72+1.89x (R^2 = 0.65)

$\hat{Y}$ = - 1.03+3.24x (R^2 = 0.80)

$\hat{Y}$ = - 5.16+6.40x (R^2 = 0.47)

$\hat{Y}$ = - 14.25+0.38x (R^2 = 0.90)

The above equations express that with every unit increase in Max T, Min T, Morn RH, WS, SS, Morn and Even VP, Evap, whitefly population and crop age, there was an increase of 2.54 (Fig. 24), 1.00 (Fig. 25), 0.31, 5.47, 2.11, 1.51 (Fig. 26), 1.89, 3.24 (Fig. 27), 6.40 (Fig. 28) and 0.38 (Fig.29)% YMD incidence.

Correlation studies further revealed that Even RH and RF exhibited positive correlation (r= 0.51 and 0.37, respectively) with disease incidence, but statistically found to be non-significant (Table 18).

Multiple regression:

R^2 obtained by computation of multiple regression equations between significant independent factors (x) of same week, preceding one and two weeks of YMD infection showed that the abiotic factors, vector population and crop age influenced the disease incidence to the extent of 96, 95 and 99%, respectively (Table 21).

3.1.2.2. Summer season

3.1.2.2.a. First year (2015-16)

First incidence of yellow mosaic disease (YMD) on soybean was observed on 21 days old crop (DOC) [20th April, 2015 *i.e.* 16^{h} SW (16/04/2015 to 22/04/2015)]. The incidence of YMD was recorded weekly as percent disease incidence (PDI) and the data are presented in Table 17, Appendix-I and illustrated in Fig.6. From Fig.6, it is evident that the YMD incidence occurred on 21 DOC (16th SW) and during that period Max T and Min T was 37.40 and 20.50^{0}C, respectively, whereas Morn RH and Even RH were 64 and 18%, respectively. Further WS, SS, Morn VP, Even VP, Evap and RF were 3.90 km/hr, 9.20 hrs, 15.50 mm, 8.90 mm while 6.60 mm and 1.20 mm, respectively, while whitefly population was 6.20 adult whiteflies/plant.

Thereafter there was a gradual increase in the disease infestation and maximum incidence (61.11%) was recorded on 70 DOC (23rd SW, 04/06/2015 to 10/06/2015), when Max T and Min T was 41.60 and 28.70^{0}C, respectively, whereas Morn RH and Even RH were 46 and 20%, respectively. Further WS, SS, Morn VP, Even VP and Evap were 6.20 km/hr, 8.30 hrs, 16.60 mm, 12.40

mm and 8.90 mm, respectively, with no RF while whitefly population was 7.00 adult whiteflies/plant.

Correlation studies:

Same week (SW):

Correlation studies of weather parameters, vector population and crop age with disease incidence of the same week revealed that Max T, Min T, Evap and crop age showed significant positive association (r= 0.74, 0.88, 0.81 and 0.92, respectively) with disease incidence (Table 19).

The regression equations being:

$\hat{Y}$ = - 212.20+5.92x (R^2 = 0.55)

$\hat{Y}$ = -130.70+6.40x (R^2 = 0.79)

$\hat{Y}$= - 74.39+11.70x (R^2 = 0.73)

$\hat{Y}$= - 20.25+1.10x (R^2 = 0.84)

The above equations express that with every unit increase in Max T, Min T, Evap and crop age there was an increase of 5.92, 6.40, 11.70 and 1.10% YMD incidence.

Correlation studies further revealed that WS, Morn VP, Even VP and vector population exhibited positive correlation (r= 0.59, 0.39, 0.50 and 0.38, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

While Morn and Even RH, SS and RF exhibited negative correlation (r= -0.52, -0.26, -0.06 and -0.15, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Preceding one week (P_1W):

Correlation studies between independent factors (*viz.* weather parameters, vector population and crop age) preceding one week of YMD infection revealed that Max T, Min T, Evap and crop age exhibited significant positive association (r= 0.74, 0.88, 0.77 and 0.95, respectively) with disease incidence (Table 19).

The regression equations being:

$\hat{Y}$ = - 211.50+6.00x (R^2 = 0.74)

$\hat{Y}$ = - 152.20+7.52x (R^2 = 0.78)

$\hat{Y}$ = -63.62+11.40x (R^2 = 0.59)

$\hat{Y}$ = - 26.70+1.41x (R^2 = 0.89)

The above equations express that with every unit increase in Max T, Min T, Evap and crop age there was an increase of 6.00, 7.52, 11.40 and 1.41% disease incidence.

Correlation studies further revealed that WS, Morn and Even VP and vector population exhibited positive correlation (r= 0.55, 0.14, 0.40 and 0.59, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

While Morn and Even RH, SS and RF exhibited negative correlation (r= -0.54, -0.23, -0.08 and -0.22, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Receding two week (P_2W):

Further, correlation studies computed between independent factors (*viz.* weather parameters, vector population and crop age) preceding two week of YMD infection revealed that Max T, Min T, Evap, vector population and crop age exhibited significant positive association (r= 0.85, 0.87, 0.76, 0.84 and 0.95, respectively) with disease incidence (Table 19).

The regression equations being:

$\hat{Y}$ = - 238+6.83x (R^2 = 0.72)

$\hat{Y}$ = - 134.50+7.08x (R^2 = 0.76)

$\hat{Y}$ = - 63.24+11.84x (R^2 = 0.57)

$\hat{Y}$ = - 18.19+5.11x (R^2 = 0.70)

$\hat{Y}$ = - 16.84+1.41x (R^2 = 0.89)

The above equations express that with every unit increase in Max T, Min T, Evap, vector population and crop there was an increase of 6.83, 7.08, 11.84, 5.11 and 1.41% disease incidence.

Correlation studies further revealed that WS, Morn and Even VP and RF exhibited positive correlation (r= 0.44, 0.11, 0.05 and 0.01, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

While Morn and Even RH and SS exhibited negative correlation (r= -0.66,-0.43 and -0.18, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Multiple regression:

R^2 obtained by computation of multiple regression equations between significant independent factors (x) of same week, preceding one and two weeks of YMD infection showed that the abiotic factors, vector population and crop age influenced the disease incidence to the extent of 84%, 98% and 97%, respectively (Table 21).

Table 19: Correlation (r) and regression coefficient (byx) of abiotic factors, whitefly population and crop age on yellow mosaic disease of soybean planted in summer season

Weather factors	Same week						P_1W						P_2W					
	2015-16		2016-17		Pooled		2015-16		2016-17		Pooled		2015-16		2016-17		Pooled	
	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx
Max. temp.(°C)	0.74**	5.92	0.62*	4.10	0.68*	5.17	0.74**	6.00	0.70*	6.64	0.77**	5.95	0.85**	6.83	0.76*	5.21	0.89**	6.13
Min. temp.(°C)	0.88**	6.40	0.87**	5.14	0.87**	6.20	0.88**	7.52	0.89**	5.53	0.94**	6.51	0.87**	7.08	0.88**	5.47	0.96**	6.62
Morning RH (%)	-0.52 NS	-	-0.50 NS	-	-0.51 NS	-	-0.54 NS	-	-0.67*	-1.31	-0.70*	-1.36	-0.66 NS	-	-0.87**	-1.35	-0.92**	-1.63
Evening RH (%)	-0.26 NS	-	0.09 NS	-	0.06 NS	-	-0.23 NS	-	0.53 NS	-	0.10 NS	-	-0.43 NS	-	-0.37 NS	-	-0.59 NS	-
Wind speed (km/hr)	0.59 NS	-	0.73**	10.19	0.77**	13.84	0.55 NS	-	0.78**	10.08	0.81**	13.46	0.44 NS	-	0.76*	14.52	0.82**	24.02
Sunshine (hrs)	-0.06 NS	-	-0.37 NS	-	-0.19 NS	-	-0.08 NS	-	-0.72*	-24.02	-0.26 NS	-	-0.18	-	-0.12 NS	-	0.24 NS	-
Morning VP (mm)	0.39 NS	-	0.70**	7.43	0.69**	8.32	0.14 NS	-	0.57 NS	-	0.54 NS	-	0.11 NS	-	0.01 NS	-	0.17 NS	-
Evening VP (mm)	0.50 NS	-	0.53 NS	-	0.56*	5.28	0.40 NS	-	0.75*	6.62	0.57 NS	-	0.05 NS	-	0.18 NS	-	-0.09 NS	-
Evaporation (mm)	0.81**	11.70	0.54 NS	-	0.65*	8.37	0.77*	11.40	0.76*	9.45	0.89**	11.43	0.76*	11.84	0.86**	9.40	0.96**	11.74
Rainfall (mm)	-0.15 NS	-	0.25 NS	-	0.31 NS	-	-0.22 NS	-	0.46 NS	-	0.31 NS	-	0.01 NS	-	-0.34 NS	-	-0.58 NS	-
Whitefly population (nos./plant)	0.38 NS	-	-0.22 NS	-	-0.17 NS	-	0.59 NS	-	-0.14 NS	-	0.03 NS	-	0.84**	5.11	0.41 NS	-	0.54 NS	-
Crop age (days)	0.92**	1.10	0.91**	0.86	0.96**	0.91	0.95**	1.41	0.95**	1.17	0.98**	1.06	0.95**	1.41	0.95**	1.17	0.98**	1.10

NS= Non-significant, *= Significant at 5%, **= Significant at 1%, P_1W= Preceding one week of infection, P_2W= Preceding two weeks of infection

3.1.2.2.b. Second year (2016-17)

First appearance of yellow mosaic disease (YMD) on soybean was observed on 28 days old crop (DOC) [29th March, 2016 *i.e.* during 13th SW (26/03/2016 to 01/04/2016)]. The incidence of YMD was recorded weekly as percent disease incidence (PDI) and the data are presented in Table 16, Appendix-II and illustrated in Fig.6. From Fig.6, it is evident that the YMD incidence occurred on 28 DOC (13th SW) and during that period Max T and Min T was 35.80 and 16.40^{0}C, respectively, whereas Morn RH and Even RH were 78 and 17%, respectively. Further WS, SS, Morn VP, Even VP, Evap and RF were 2.30 km/hr, 10.00 hrs, 12.90 mm, 7.10 mm, 4.70 mm and 8.00 mm, respectively, while whitefly population was 5.90 adult whiteflies/plant.

Thereafter the incidence rapidly increased and attained maximum incidence (67.78%) on 91 DOC (22nd SW, 28/05/2016 to 03/06/2016), when Max T and Min T was 39.80 and 24.60^{0}C, respectively, whereas Morn RH and Even RH were 62 and 27%, respectively. Further WS, SS, Morn VP, Even VP, Evap and RF were 6.30 km/hr, 8.90 hrs, 18.90 mm, 14.50 mm, 6.50 mm and 15.20 mm, respectively while whitefly population was 0.40 adult whitefly/plant.

Correlation studies:

Same week (SW):

Correlation studies with same weather parameters, vector population and crop age with disease incidence of the same week revealed that Max T, Min T, WS, Morn VP and crop age exhibited significant positive association (r= 0.62, 0.87, 0.73, 0.70 and 0.91, respectively) with disease incidence (Table 19).

The regression equations being:

$\hat{Y}$ = - 135.60+4.10x (R^2 = 0.39)

$\hat{Y}$ = -85.78+5.14x (R^2 = 0.76)

$\hat{Y}$= - 27.58+10.19x (R^2 = 0.54)

$\hat{Y}$= - 77.58+7.43x (R^2 = 0.49)

$\hat{Y}$= - 2.68+0.86x (R^2 = 0.83)

The above equations express that with every unit increase in Max T, Min T, WS, Morn VP and crop age there was an increase of 4.10, 5.14, 10.19, 7.43 and 0.86% disease incidence.

Correlation studies further revealed that Even RH, Even VP, Evap and RF exhibited positive correlation (r= 0.09, 0.53, 0.54 and 0.25, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

While Morn RH, SS and vector population exhibited negative correlation (r= -0.50, -0.37 and -0.22, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Preceding one week (P_1W):

Correlation studies between independent factors (*viz.* weather parameters, vector population and crop age) preceding one week of YMD infection revealed that Max T, Min T, WS, Even VP, Evap and crop age exhibited significant positive association (r= 0.70, 0.89, 0.78, 0.75, 0.76 and 0.95, respectively) with disease incidence (Table 19).

The regression equations being:

$\hat{Y}$ = - 235.00+6.64x (R^2 = 0.49)

$\hat{Y}$ = - 90.73+5.53x (R^2 = 0.80)

$\hat{Y}$ = -21.11+10.08x (R^2 = 0.60)

$\hat{Y}$ = - 30.06+6.62x (R^2 = 0.57)

$\hat{Y}$ = -49.72+9.45x (R^2 = 0.58)

$\hat{Y}$ = 33.73+1.17x (R^2 = 0.91)

The above equations express that with every unit increase in Max T, Min T, WS, Even VP, Evap and crop age there was an increase of 6.64, 5.53, 10.08, 6.62, 9.45 and 1.17% disease incidence.

Correlation studies further revealed that Even RH, Morn VP and RF exhibited positive correlation (r= 0.53, 0.57 and 0.46, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Further, Morn RH and SS showed significant negative correlation (r= -0.67 and -0.72, respectively) with disease incidence (Table 19).

The regression equation being:

$\hat{Y}$ = 97.15-1.31x (R^2 = 0.44)

$\hat{Y}$ = 259.90-24.02x (R^2 = 0.59)

The above equations express that with every unit increase in Morn RH and SS there was a decrease of 1.31 and 24.02% disease incidence.

While vector population negative correlation (r= -0.14) with disease incidence, but statistically found to be non-significant (Table 19).

Preceding two week (P_2W):

Further, correlation studies computed between independent factors (*viz.* weather parameters, vector population and crop age) preceding two week of YMD infection revealed that the Max T, Min T, WS, Evap and crop age exhibited significant positive association (r= 0.76, 0.88, 0.76, 0.86 and 0.95, respectively) with disease incidence (Table 19).

The regression equations being:

$\hat{Y}$ = -173.30+5.21x (R^2 = 0.58)

$\hat{Y}$ = - 82.94+5.47x (R^2 = 0.77)

$\hat{Y}$ = - 35.39+14.52x (R^2 = 0.57)

$\hat{Y}$ = - 43.60+9.40x (R^2 = 0.75)

$\hat{Y}$ = - 25.53+1.17x (R^2 = 0.91)

The above equations express that with every unit increase in Max T, Min T, Morn VP, Evap and crop age there was an increase of 5.21, 5.47, 14.52, 9.40 and 1.17% disease incidence.

Correlation studies further revealed that Morn and Even VP and vector population exhibited positive correlation (r= 0.01, 0.18 and 0.41, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Further, Morn RH expressed significant negative correlation (-0.87) with disease incidence (Table 19).

The regression being:

$\hat{Y}$ = 103.4-1.35x (R^2 = 0.75)

The above equation express that with every unit increase in Morn RH there was an decrease of 1.35% disease incidence.

While Even RH, SS and RF exhibited negative correlation (r= -0.37, -0.12 and -0.34, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Multiple regression:

R^2 obtained by computation of multiple regression equations between significant independent factors (x) of same week, preceding one and two weeks of YMD infection showed that the abiotic factors, vector population and crop age were responsible for influencing disease incidence to the extent of 99%, 100% and 98%, respectively (Table 21).

3.1.2.2.c. Pooled data

Pooled analysis of the data showed that the first incidence of YMD was observed when the crop age was 24.5±3.5 days (Table 17 and Fig.6). During the first incidence the Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 36.6±0.8^{0}C, 18.45±2.05^{0}C, 71±7%, 17.5±0.5%, 3.1±0.8 km/hr, 9.6±0.4 hrs, 14.2±1.3 mm, 8±0.9 mm, 5.65±0.95 mm, 5±3.5 mm and 6.05±0.15 adult whiteflies/plant, respectively.

There was a gradual increase in the disease infection and it attained maximum (64.45±3.33%) on 80.5±10.5 DOC, when Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap and vector population were 40.7±0.9^{0}C, 26.65±2.05^{0}C, 54±8%, 23.5±3.5%, 6.25±0.05 km/hr, 8.6±0.3 hrs, 17.75±1.15 mm, 13.45±1.05 mm, 7.7±1.2 mm, 8.1±7.6 mm and 3.7±3.3 adult whiteflies/plant, respectively.

Correlation studies:

Same week (SW):

Correlation studies of weather parameters, vector population and crop age with disease incidence of the same week revealed that Max T, Min T, WS, Morn and Even VP, Evap and crop age showed significant positive association (r= 0.68, 0.87, 0.77, 0.69, 0.56, 0.65 and 0.96, respectively) with disease incidence (Table 19).

The regression equations being:

$\hat{Y}$ = - 176.40+5.17x (R^2 = 0.47)

$\hat{Y}$ = -11.00+6.20x (R^2 = 0.76)

$\hat{Y}$ = -47.11+13.84x (R^2 = 0.60)

$\hat{Y}$ = -88.10+8.32x (R^2 = 0.48)

$\hat{Y}$ = -27.92+5.28x (R^2 = 0.32)

$\hat{Y}$ = -38.74+8.37x (R^2 = 0.42)

$\hat{Y}$ = -18.32+0.91x (R^2 = 0.93)

The above equations express that with every unit increase in Max T, Min T, WS, Morn and Even VP, Evap and crop there was an increase of 5.17 (Fig. 30), 6.20 (Fig. 31), 13.84 (Fig. 32), 8.32, 5.28, 8.37 (Fig. 33) and 0.91 (Fig. 34)% YMD incidence.

Correlation studies further revealed that Even RH and RF exhibited positive correlation (r= 0.06 and 0.31, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Further, morn RH, SS and vector population exhibited negative correlation (r= -0.51, -0.19 and -0.17, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Preceding one week (P_1W):

Correlation studies between independent factors (*viz.* weather parameters, vector population and crop age) preceding one week of YMD infection revealed that Max T, Min T, WS, Evap and crop age exhibited significant positive association (r= 0.77, 0.94, 0.81, 0.89 and 0.98, respectively) with disease incidence (Table 19).

The regression equations being:

$\hat{Y}$ = - 204.70+5.95x (R^2 = 0.59)

$\hat{Y}$ = - 117.80+6.51x (R^2 = 0.89)

$\hat{Y}$ = -40.16+13.46x (R^2 = 0.66)

$\hat{Y}$ = - 61.88+11.43x (R^2 = 0.78)

$\hat{Y}$ = - 20.98+1.06x (R^2 = 0.96)

The above equations express that with every unit increase in Max T, Min T, WS, Evap and crop age there was an increase of 5.95, 6.51, 13.46, 11.43 and 1.06% disease incidence (Fig. 30, 31, 32, 33 and 34, respectively).

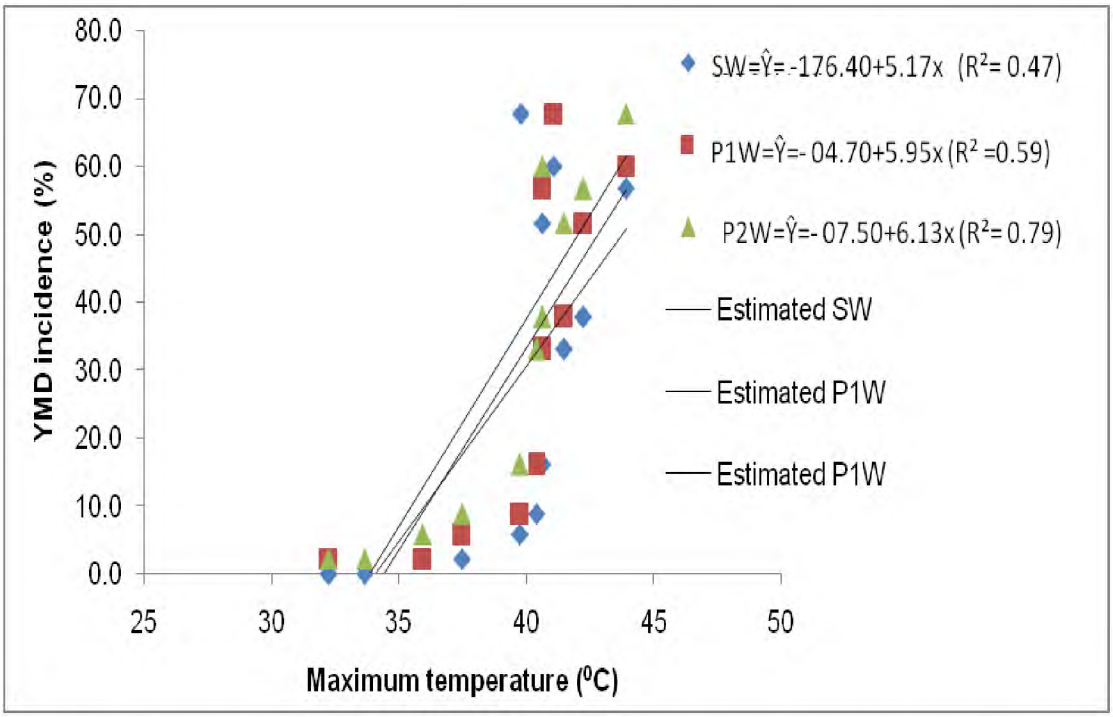

Fig. 30: Regression of YMD incidence on maximum temperature during summer soybean (Pooled)

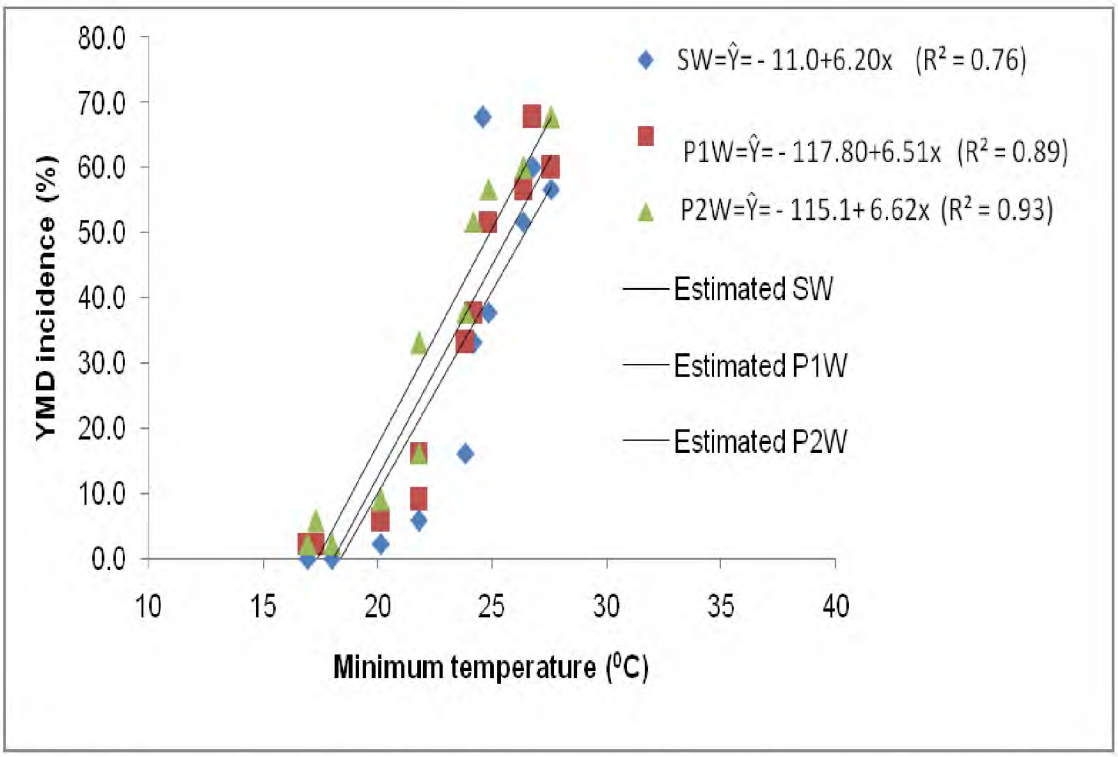

Fig. 31: Regression of YMD incidence on minimum temperature during summer soybean (Pooled)

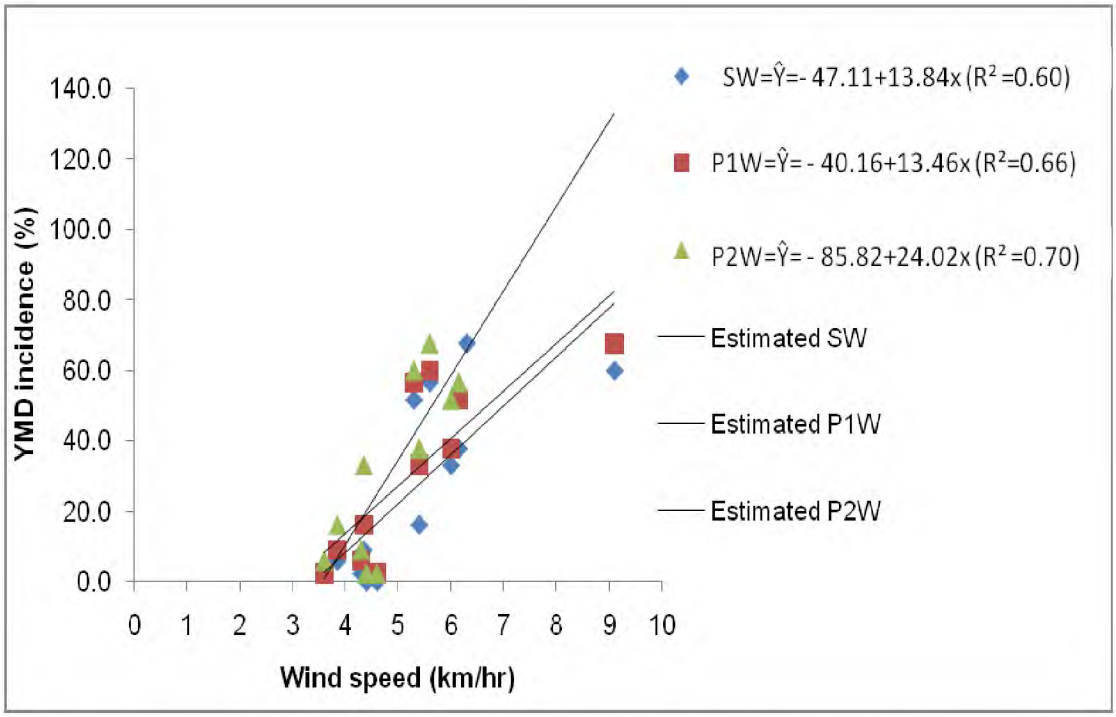

Fig. 32: Regression of YMD incidence on wind speed during summer soybean (Pooled)

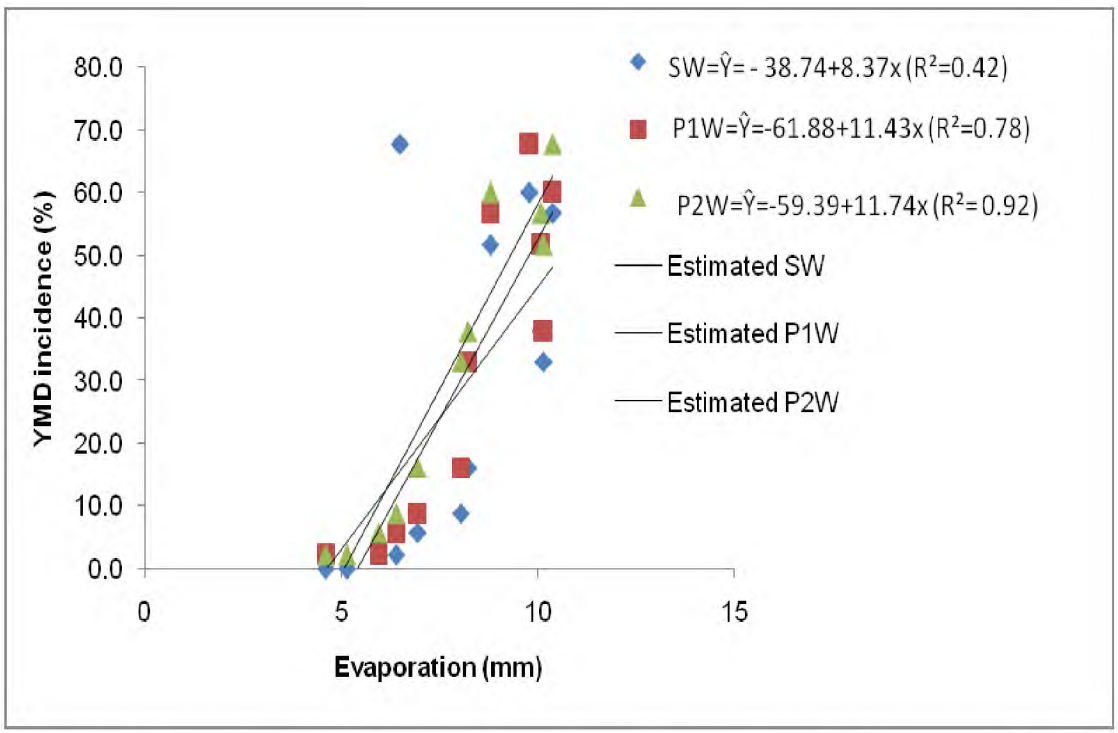

Fig. 33: Regression of YMD incidence on evaporation during summer soybean (Pooled)

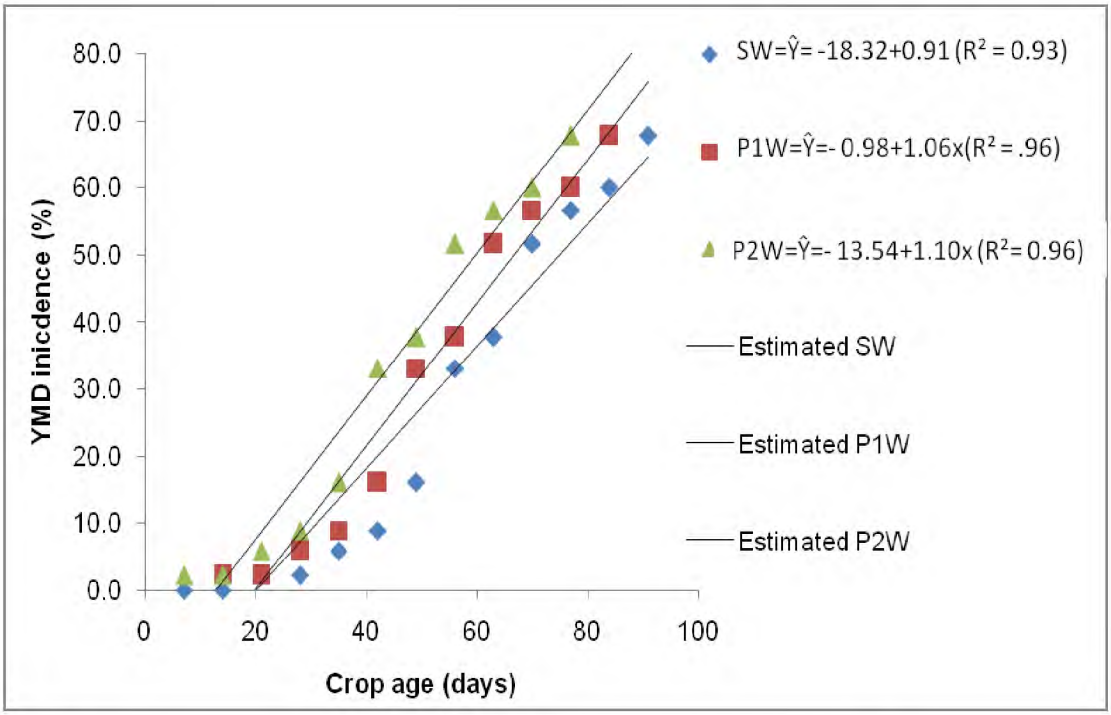

Fig. 34: Regression of YMD incidence on crop age during summer soybean (Pooled)

Correlation studies further revealed that Even RH, Morn and Even VP, RF and vector population exhibited positive correlation (r= 0.10, 0.54, 0.57, 0.31 and 0.03, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Further, Morn RH showed significant negative correlation (r= -0.70) with disease incidence (Table 19).

The regression equation being:

$\hat{Y}$ = 101.50-1.36x (R^2 = 0.48)

The above equation express that with every unit increase in Morn RH there was a decrease of 1.36% disease incidence.

While SS exhibited negative correlation (r= -0.26) with disease incidence, but statistically found to be non-significant (Table 19).

Preceding two week (P_2W):

Further, correlation studies computed between independent factors (*viz.* weather parameters, vector population and crop age) preceding two week of YMD infection revealed that Max T, Min T, WS, Evap and crop age exhibited significant positive association (r= 0.89 0.96, 0.82, 0.96 and 0.98, respectively) with disease incidence (Table 19).

The regression equations being:

$\hat{Y}$ = -207.50+6.13x (R^2 = 0.79)

$\hat{Y}$ = - 115.10+6.62x (R^2 = 0.93)

$\hat{Y}$ = - 85.82+24.02x (R^2 = 0.70)

$\hat{Y}$ = - 59.39+11.74x (R^2 = 0.92)

$\hat{Y}$ = -13.54+1.10x (R^2 = 0.96)

The above equations express that with every unit increase in Max T, Min T, WS, Evap and crop age, there was an increase of 6.13, 6.62, 24.02, 11.74 and 1.10% disease incidence (Fig. 30, 31, 32, 33 and 34, respectively).

Correlation studies further revealed that SS, Morn VP and vector population exhibited positive correlation (r= 0.24, 0.17 and 0.54, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Further, Morn RH showed significant negative correlation (r= -0.92) with disease incidence (Table 19).

The regression equation being:

$\hat{Y}$ = 118.00-1.63x (R^2 = 0.84)

The above equation expresses that with every unit increase in Morn RH and SS there was a decrease of 1.63 % disease incidence.

While Even RH, Even VP and RF exhibited negative correlation (r= -0.59, -0.09 and -0.58, respectively) with disease incidence, but statistically found to be non-significant (Table 19).

Multiple regression:

R^2 obtained by computation of multiple regression equations between significant independent factors (x) of same week, preceding one and two weeks of YMD infection showed that the abiotic factors, vector population and crop age influenced the disease incidence to the extent of 99%, 98% and 99%, respectively (Table 21).

3.1.2.3 *Kharif* season

3.1.2.3.a. First year (2015-16)

First incidence of yellow YMD on soybean was observed on 21 days old crop (DOC) [3rd August, 2015 *i.e.* 31st SW (30/07/2015 to 05/08/2015)]. The YMD incidence was recorded weekly as percent disease incidence and

the data are presented in Table 17, Appendix-I and illustrated in Fig.13. From Fig.13, it is evident that the first incidence of YMD occurred on 21 DOC (31st SW) and during that period Max T and Min T was 29.80 and 23.60^{0}C, respectively, whereas Morn RH and Even RH were 90 and 70%, respectively. Further, WS, SS, Morn VP, Even VP, Evap and RF were 8.30 km/hr, 4.70 hrs, 21.30 mm, 20.20mm, 3.40 mm and149.40 mm, respectively, while whitefly population was 2.40 adult whiteflies/plant.

Thereafter, there was a gradual increase in the disease infection and maximum incidence (100%) was recorded on 56 DOC (36th SW, 03/09/2015 to 09/09/2015), when Max T and Min T was 32.20 and 24.20^{0}C, respectively, whereas Morn RH and Even RH were 87 and 57%, respectively. Further, WS, SS, Morn VP, Even VP, Evap and RF were 3.50 km/hr, 6.70 hrs, 21.50 mm, 20.80 mm, 3.40 mm and 8.20 mm, respectively, while whitefly population was 11.20 adult whiteflies/plant.

Correlation studies:

Same week (SW):

Correlation studies of weather parameters, vector population and crop age with disease incidence revealed that Max T, SS, Evap, vector population and crop age showed significant positive association (r= 0.69, 0.72, 0.66, 0.84 and 0.93, respectively) with disease incidence (Table 20).

The regression equations being:

$\hat{Y}$ = - 645.60+22.09x (R^2 = 0.48)

$\hat{Y}$ = -20.30+13.06x (R^2 = 0.52)

$\hat{Y}$= - 217+76.30x (R^2 = 0.43)

$\hat{Y}$= - 11.60+10.90x (R^2 = 0.70)

$\hat{Y}$= - 17.17+1.55x (R^2 = 0.89)

The above equations express that with every unit increase in Max T, SS, Evap, vector population and crop age there was an increase of 22.09, 13.06, 76.30, 10.90 and 1.55% YMD infection.

Correlation studies of same week of weather parameters, vector population and crop age revealed that Even RH, WS and RF showed

significant negative association (r= -0.66, -0.62 and -0.61, respectively) with disease incidence.

The regression equations being:

$\hat{Y}$= 182.70- 2.08x (R^2 = 0.43)

$\hat{Y}$= 132.50- 15.84x (R^2 = 0.40)

$\hat{Y}$= 84.38-0.52x (R^2 = 0.37)

The above equations express that with every unit increase in Even RH, WS and RF there was an increase of 2.08, 15.84 and 0.52% YMD infection.

While Min T, Morn RH, Morn and Even VP exhibited negative correlation (r= -0.55, -0.14, - 0.49 and - 0.53, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Preceding (P_1W):

Correlation studies between independent factors (*viz.* weather parameters, vector population and crop age) preceding one week of YMD infection revealed that Max T, Evap, vector population and crop age exhibited significant positive association (r= 0.69, 0.63, 0.76 and 0.89, respectively) with disease incidence (Table 20).

The regression equations being:

$\hat{Y}$ = - 211.50+24.27x (R^2 = 0.74)

$\hat{Y}$ = - 152.20+60.26x (R^2 = 0.78)

$\hat{Y}$ = -63.62+10.10x (R^2 = 0.59)

$\hat{Y}$ = - 7.60+1.57x (R^2 = 0.79)

The above equations express that with every unit increase in Max T, Min T, Evap and crop age there was an increase of 24.27, 60.26, 10.10 and 1.57% disease incidence.

Correlation studies further revealed that SS exhibited positive correlation (r= 0.53) with disease incidence, but statistically found to be non-significant (Table 20).

While Min T, Morn and Even RH, WS, Morn and Even VP and RF exhibited negative correlation (r= -0.42, -0.04, -0.50, -0.50, -0.32, -0.33 and -0.50, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Preceding two week (P_2W):

Further, correlation studies computed between independent factors (*viz.* weather parameters, vector population and crop age) preceding two week of YMD incidence revealed that vector population and crop age exhibited significant positive association (r= 0.76 and 0.89, respectively) with disease incidence (Table 20).

The regression equations being:

$\hat{Y} = 17.41+8.17x$ ($R^2 = 0.58$)

$\hat{Y} = 3.414+1.57x$ ($R^2 = 0.79$)

The above equations express that with every unit increase in vector population and crop age there was an increase of 8.17 and 1.57% disease incidence.

Correlation studies further revealed that the Max T, Morn RH, SS and Evap exhibited positive correlation (r= 0.54, 0.08, 0.54 and 0.46, respectively) with disease incidence, but, statistically found to be non-significant (Table 20).

While Min T, Even RH, WS, Morn and Even VP and RF exhibited negative correlation (r= -0.33,-0.42, -0.38, -0.17, -0.18 and -0.49, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Multiple regression:

R^2 obtained by computation of multiple regression equations between significant independent factors (x) of same week, preceding one and two weeks of YMD infection showed that the abiotic factors, vector population and crop age influenced the disease incidence to the extent of 95%, 88% and 79%, respectively (Table 21).

3.1.2.3.b. Second year (2016-17)

First appearance of YMD on soybean was observed on 28 days old crop (DOC) [29th July, 2016 *i.e.* 30th SW (23/07/2016 to 29/07/2016)]. The YMD incidence was recorded weekly as percent disease incidence and the data are presented in Table 17, Appendix-II and illustrated in Fig.13. From Fig.13, it is evident that the first incidence of YMD occurred on 28 DOC (13th SW) and during that period Max T and Min T was 31.70 and 24^{0}C, respectively, whereas Morn RH and Even RH were 91 and 67%, respectively.

Further, WS, SS, Morn VP, Even VP, Evap and RF were 4.50 km/hr, 4.70 hrs, 23.20 mm, 22.50 mm, 3.70 mm and 61.80 mm, respectively, while whitefly population was 10.50 adult whiteflies/plant.

Thereafter, the incidence gradually increased and attained maximum (62.22%) on 91 DOC (39^{th} SW, 24/09/2016 to 30/09/2016), when Max T and Min T was 29.90 and 23.50^{0}C, respectively, whereas Morn RH and Even RH were 94 and 83%, respectively. Further, WS, SS, Morn VP, Even VP, Evap and RF were 4.00 km/hr, 4.60 hrs, 22.30 mm, 22.60 mm, 3.00 mm and 52.40 mm, respectively, while whitefly population recorded was 0.20 adult whitefly/plant.

Correlation studies:

Same week (SW):

Correlation studies of weather parameters, vector population and crop age with disease incidence of the same week revealed that crop age exhibited significant positive association (r= 0.89) with disease incidence (Table 20).
The regression equation being:

$\hat{Y}$ = - 18.59+0.74x (R^2 = 0.80)

The above equation express that with every unit increase in crop age there was an increase of 0.74% disease incidence.

Correlation studies further revealed that Max T, Min T, SS and Evap exhibited positive correlation (r= 0.38, 0.03, 0.38 and 0.19, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Table 20: Correlation (r) and regression coefficient (byx) of abiotic factors, whitefly population and crop age on yellow mosaic disease of soybean planted in *Kharif* season

Weather factors	Same week						P_1W						P_2W					
	2015-16		2016-17		Pooled		2015-16		2016-17		Pooled		2015-16		2016-17		Pooled	
	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx	r	byx
Max. temp.(°C)	0.69**	22.09	0.38 NS	-	0.55 NS	-	0.69*	24.27	0.48 NS	-	0.38 NS	-	0.54 NS	-	0.23 NS	-	0.30 NS	-
Min. temp.(°C)	-0.55 NS	-	0.03 NS	-	-0.82**	-26.34	-0.42 NS	-	0.005 NS	-	-0.83**	-33.32	-0.33 NS	-	-0.33 NS	-	-0.71*	-40.86
Morning RH (%)	-0.14 NS	-	-0.06 NS	-	-0.38 NS	-	-0.04 NS	-	-0.43 NS	-	-0.39 NS	-	0.08 NS	-	-0.77**	-9.38	-0.42 NS	-
Evening RH (%)	-0.66*	-2.08	-0.28 NS	-	-0.72**	-2.44	-0.50 NS	-	-0.57 NS	-	-0.56 NS	-	-0.42 NS	-	-0.49 NS	-	-0.49 NS	-
Wind speed (km/hr)	-0.62*	-15.84	-0.68*	-9.87	-0.69*	-14.12	-0.50 NS	-	-0.47 NS	-	-0.50 NS	-	-0.38 NS	-	-0.27 NS	-	-0.51 NS	-
Sunshine (hrs)	0.72**	13.06	0.38 NS	-	0.71**	11.67	0.53 NS	-	0.28 NS	-	0.50 NS	-	0.54 NS	-	0.13 NS	-	0.47 NS	-
Morning VP (mm)	-0.49 NS	-	-0.01 NS	-	-0.81**	-24.05	-0.32 NS	-	-0.10 NS	-	-0.76**	-25.84	-0.17 NS	-	-0.50 NS	-	-0.58 NS	-
Evening VP (mm)	-0.53 NS	-	-0.25 NS	-	-0.78**	-13.08	-0.33 NS	-	-0.36 NS	-	-0.64*	-12.45	-0.18 NS	-	-0.65*	-15.16	-0.51 NS	-
Evaporation (mm)	0.66*	76.30	0.19 NS	-	0.35 NS	-	0.63*	60.26	0.19 NS	-	0.26 NS	-	0.46 NS	-	0.28 NS	-	0.41 NS	-
Rainfall (mm)	-0.61*	-0.52	-0.52 NS	-	-0.62*	-0.29	-0.50 NS	-	-0.56 NS	-	-0.40 NS	-	-0.49 NS	-	-0.46 NS	-	-0.53 NS	-
Whitefly population (nos./plant)	0.84**	10.90	-0.14 NS	-	0.43 NS	-	0.76**	10.10	-0.07 NS	-	0.48 NS	-	0.76**	8.17	0.37 NS	-	0.72*	5.50
Crop age (days)	0.93**	1.55	0.89**	0.74	0.98**	1.14	0.89**	1.57	0.94**	1.04	0.98**	1.24	0.89**	1.57	0.94**	5.21	0.98**	1.25

NS= Non-significant, *= Significant at 5%, **= Significant at 1%, P_1W= Preceding one week of infection, P_2W= Preceding two weeks of infection

Table 21: Multiple regression of abiotic factors, whitefly population and crop age on yellow mosaic disease of soybean planted in different seasons

Season	Year	Period	Constant	Max. temp (^{0}C)	Min. (^{0}C)	Morning RH (%)	Evening RH (%)	Wind speed (km/hr)	Sunshine (hrs)	Morning VP (mm)	Evening VP (mm	Evaporation (mm)	Rainfall (mm)	Whitefly population (nos./plant)	Crop age (days)	R^2
Rabi	2014-15	SW	13.490	0.914	-1.800	-0.638				3.561		0.607		-1.920	0.199	0.990
	2015-16	SW	76.125	-2.593	0.689	-0.408	-0.562		1.274	3.864		-0.204		0.461	-0.029	0.997
	Pooled - SW		-5.786	0.604	2.388					-4.373		1.021		-4.403	0.340	0.969
	2014-15	P_1W	86.937	-0.321	-5.243	-1.490				8.997		3.286		0.386	0.269	0.989
	2015-16	P_1W	-25.068	-0.212	-0.003	0.190				-0.249		2.025			0.291	0.985
	Pooled - P_1W		43.483	-3.213	-0.168							1.561		4.667	0.584	0.955
	2014-15	P_2W	-3.601	-1.319	-1.662					3.281	-1.085			2.018	0.570	0.991
	2015-16	P_2W	-15.857	-1.293	2.033	0.425				-2.995		2.609			0.421	0.995
	Pooled - P_2W		-82.945	2.264	5.623	1.024		5.067	-2.761	-11.782	-1.438	-0.155		-2.583	0.432	0.999
Summer	2015-16	SW	-14.806	-5.294	7.749							7.585			0.021	0.843
	2016-17	SW	22.856	-1.599	2.886			-0.625		-1.584				-2.224		0.990
	Pooled - SW		110.043	-3.666	-1.612			-8.766		-2.279	4.750	7.733			1.331	0.991
	2015-16	P_1W	149.655	-6.515	2.028							1.305			2.036	0.980
	2016-17	P_1W	937.327	-4.761	11.618	-3.006		33.142	-41.712		-23.671	-49.659		-1.057	1.036	1.000
	Pooled - P_1W		114.064	-4.981	1.821	-0.174		-0.958				4.717			0.990	0.986
	2015-16	P_2W	8.751	1.659	-4.425							0.667		-5.177	3.070	0.975
	2016-17	P_2W	-51.416	2.121	-3.999	0.125		10.198				-9.192		-0.875	2.288	0.985
	Pooled - P_2W		180.350	-5.563	1.699	-0.805		0.155				5.642			0.683	0.993
Kharif	2015-16	SW	202.586	-4.810			-1.402	6.035	-9.217			6.717	-0.159	6.618	1.260	0.952
	2016-17	SW	-1.917					-2.178							0.660	0.810
	Pooled - SW		415.046		-10.415		-1.075	2.939	2.242	-26.632	21.525		-0.123		0.701	0.981
	2015-16	P_1W	698.761	-22.015								-21.797		7.243	1.951	0.888
	2016-17	P_1W	-31.273												1.038	0.881
	Pooled - P_1W		43.111		3.224					-12.902	6.717				1.280	0.992
	2015-16	P_2W	3.050											0.631	1.485	0.794
	2016-17	P_2W	254.734			-2.846					-0.511				0.846	0.914
	Pooled - P_2W		-210.127		8.433									-0.622	1.466	0.964

Further, WS expressed significant negative correlation (-0.68) with disease incidence (Table 20).

The regression being:

$\hat{Y}$ = 74.74-9.87x (R^2 = 0.47)

The above equation expresses that with every unit increase in WS there was decrease of 9.87% disease incidence.

While Morn and Even RH, Morn and Even VP, RF and vector population exhibited negative correlation (r= -0.06, -0.28, -0.01, -0.25, -0.52 and -0.14, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Preceding one week (P_1W):

Correlation studies between independent factors (*viz.* weather parameters, vector population and crop age) preceding one week of YMD infection revealed that crop age exhibited significant positive association (r= 0.94) with disease incidence (Table 20).

The regression equation being:

$\hat{Y}$ = - 31.27+1.04x (R^2 = 0.88)

From the above equations it may be expressed that with every unit increase in crop age there was an increase of 1.04% disease incidence (Fig. 33).

Correlation studies further revealed that Max T, Min T, SS and Evap exhibited positive correlation (r= 0.48, 0.005, 0.28 and 0.19, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Further, correlation revealed that Morn and Even RH, WS, Morn and Even VP, RF and vector population exhibited negative correlation (r= -0.43, -0.57, -0.47, -0.10, -0.36, -0.56 and -0.07, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Preceding two week (P_2W):

Further, correlation studies computed between independent factors (*viz.* weather parameters, vector population and crop age) preceding two week of YMD infection revealed that crop age exhibited significant positive association (r= 0.94) with disease incidence (Table 20).

The regression equations being:

$\hat{Y}$ = -173.30+5.21x (R^2 = 0.58)

The above equation expresses that with every unit increase in crop age there was an increase of 5.21% disease incidence.

Correlation studies further revealed that Max T, SS, Evap and vector population exhibited positive correlation (r= 0.23, 0.13, 0.28 and 0.37, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Further, Morn RH and Even VP expressed significant negative correlation (-0.77 and -0.65, respectively) with disease incidence (Table 20).

The regression being:

$\hat{Y}$ = 875.00-9.38x (R^2 = 0.60)

$\hat{Y}$ = 367.30-15.16x (R^2 =42)

The above equations express that with every unit increase in Morn RH there was an decrease of 9.38 and 15.16% disease incidence.

While Min T, Even RH, WS, Morn VP and RF exhibited negative correlation (r= -0.33, -0.49, -0.27, -0.50, and -0.46, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Multiple regression:

R^2 obtained by computation of multiple regression equations between significant independent factors (x) of same week, preceding one and two weeks of YMD infection showed that the abiotic factors, vector population and crop age influenced the disease incidence to the extent of 81%, 88% and 91%, respectively (Table 21).

3.1.2.2.c. Pooled data

Pooled analysis of the data showed that the first incidence of YMD was observed when the crop age was 24.5±3.5 days (Table 17 and Fig. 13). During the first incidence the Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 30.75±0.95^{0}C, 23.8±0.2^{0}C, 90.5±0.5%, 68.5±1.5%, 6.4±1.9 km/hr, 4.7 hrs, 22.25±0.95 mm, 21.35±1.15 mm, 3.55±0.15 mm, 105.85±44.05 mm and 6.45±4.05 adult whiteflies/plant, respectively.

There was a gradual increase in the disease infection and it attained maximum (81.11±18.89%) on 73.5±17.5 DOC, when Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 31.05±1.15^{0}C, 23.85±0.35^{0}C, 90.5±3.5%, 70±13%, 3.75±0.25 km/hr, 5.65±1.05 hrs, 21.9±0.4 mm, 21.7±0.9 mm, 3.20±0.20 mm, 30.55±21.85 mm and 5.7±5.50 adult whiteflies/plant, respectively.

Correlation studies:

Same week (SW):

Correlation studies of weather parameters, vector population and crop age with disease incidence of the same week revealed that SS and crop age showed significant positive association (r= 0.71 and 0.98, respectively) with disease incidence (Table 20).

The regression equations being:

$\hat{Y}$ = - 18.66+11.67x (R^2 = 0.50)

$\hat{Y}$ = -17.69+1.14x (R^2 = 0.96)

The above equations express that with every unit increase in SS and crop age there was an increase of 11.67 and 1.14% YMD incidence (Fig 35 and 36, respectively).

Correlation studies further revealed that Max T, Evap and vector population exhibited positive correlation (r= 0.55, 0.35 and 0.43, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Further, Min T, Even RH, WS, Morn and Even VP and RF showed significant negative correlation (r= -0.82, -0.72, -0.69, -0.81 -0.78 and -0.62, respectively) with disease incidence (Table 20).

The regression equation being:

$\hat{Y}$ = 647.50 -26.34x (R^2 = 0.68)

$\hat{Y}$ = 201.80 -2.44x (R^2 = 0.52)

$\hat{Y}$ = 111.90 -14.12x (R^2 = 0.47)

$\hat{Y}$ = 559.20 -24.05x (R^2 = 0.66)

$\hat{Y}$ = 319.30 -13.08x (R^2 = 0.61)

$\hat{Y}$ = 62.12 -0.29x (R^2 = 0.38)

The above equations express that with every unit increase in Min T, Even RH, WS, Morn and Even VP and RF, there was a decrease of 26.34 (Fig. 37), 2.44, 14.12 (Fig. 38), 24.05, 13.08 and 0.29% disease incidence.

While Morn RH exhibited negative correlation (r= -0.38) with disease incidence, but statistically found to be non-significant (Table 20).

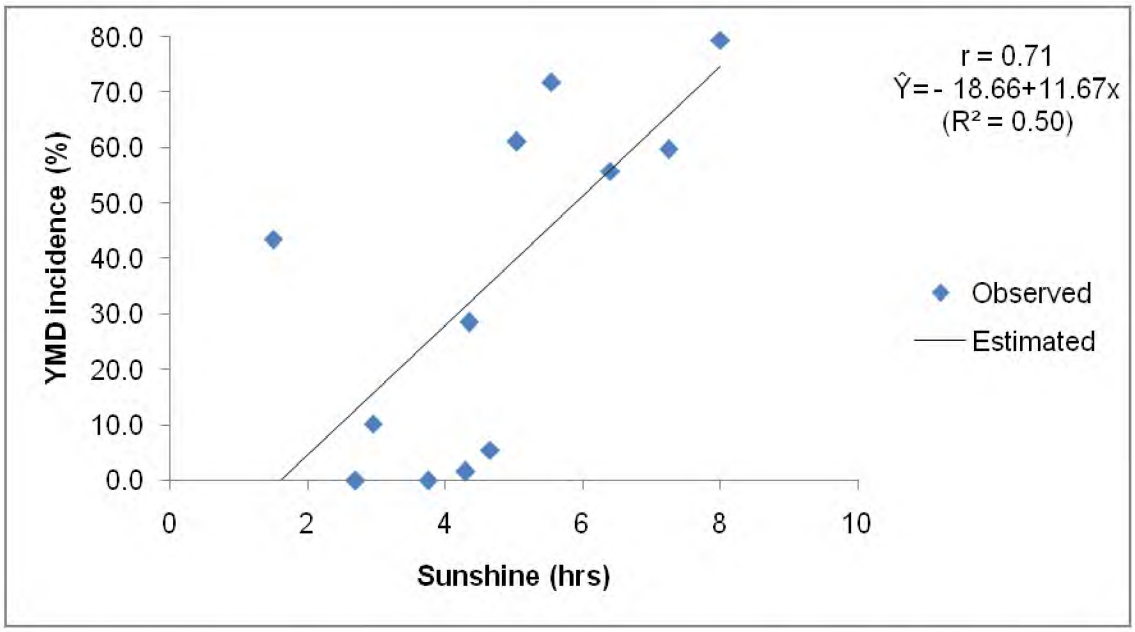

Fig. 35: Regression of YMD incidence on sunshine during *kharif* soybean (Pooled)

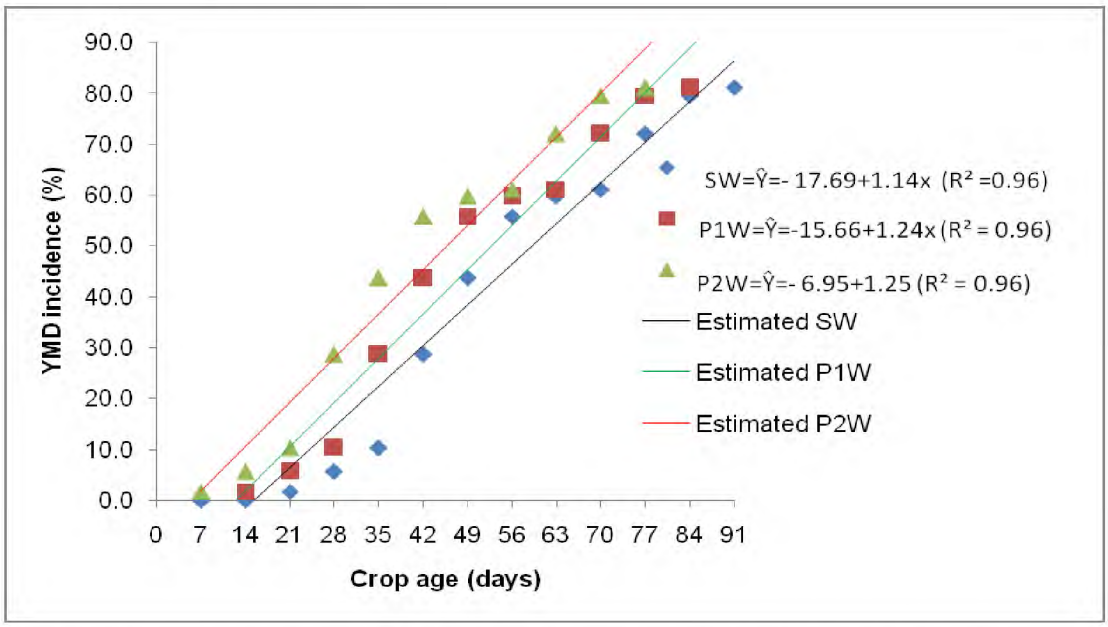

Fig. 36: Regression of YMD incidence on crop age during *kharif* soybean (Pooled)

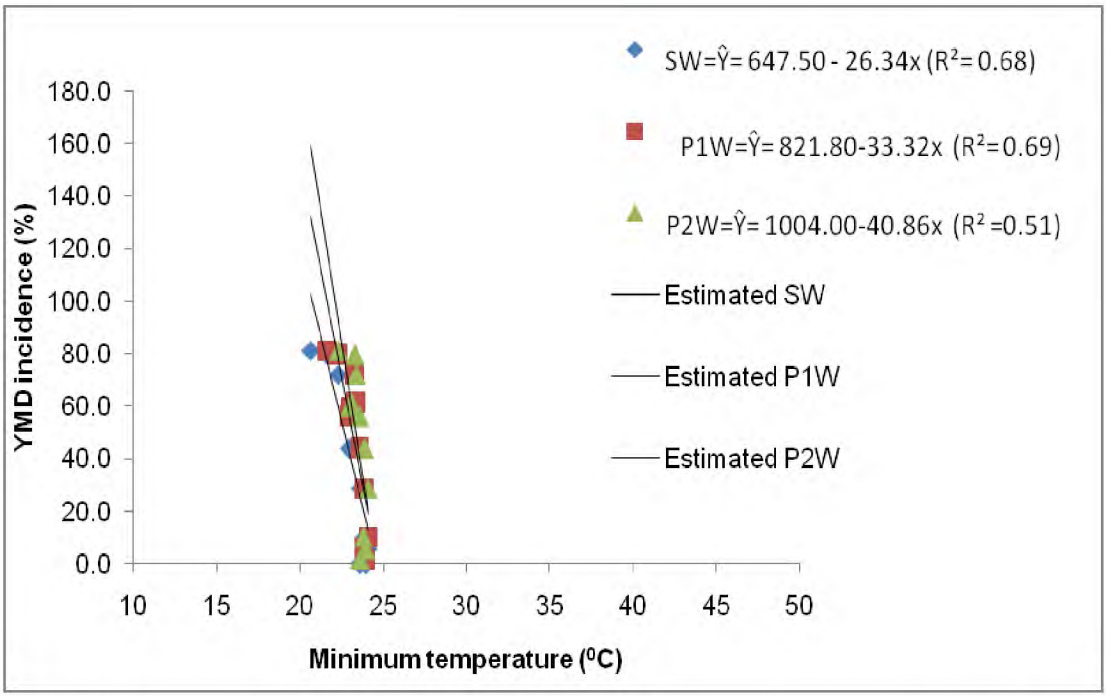

Fig. 37: Regression of YMD incidence on minimum temperature during *kharif* soybean (Pooled)

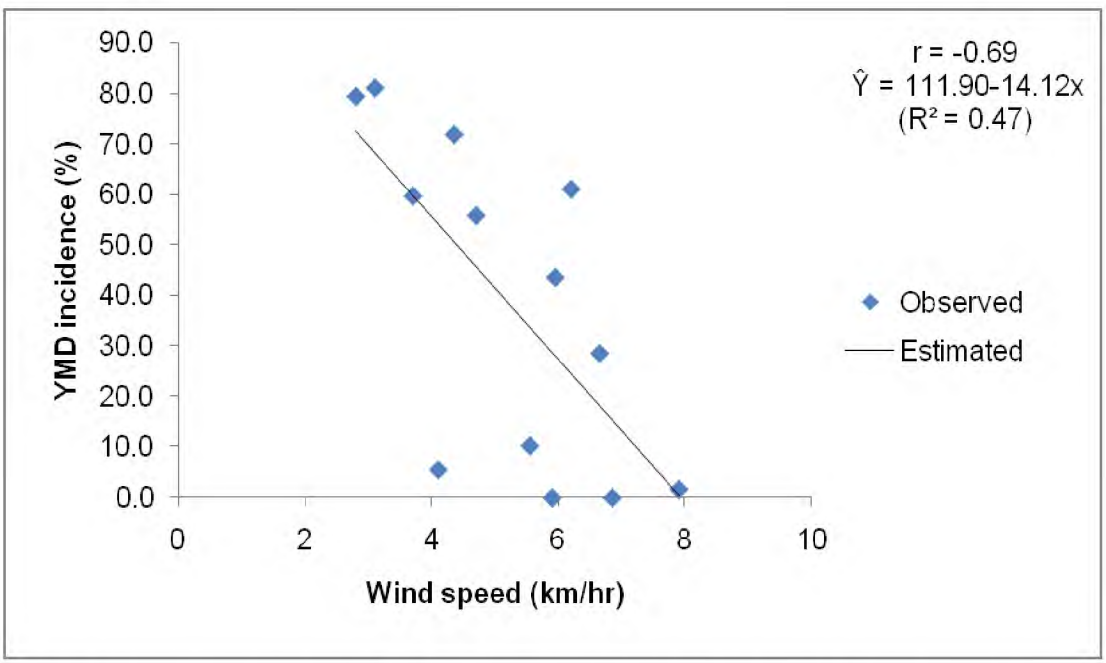

Fig. 38: Regression of YMD incidence on wind speed during *kharif* soybean (Pooled)

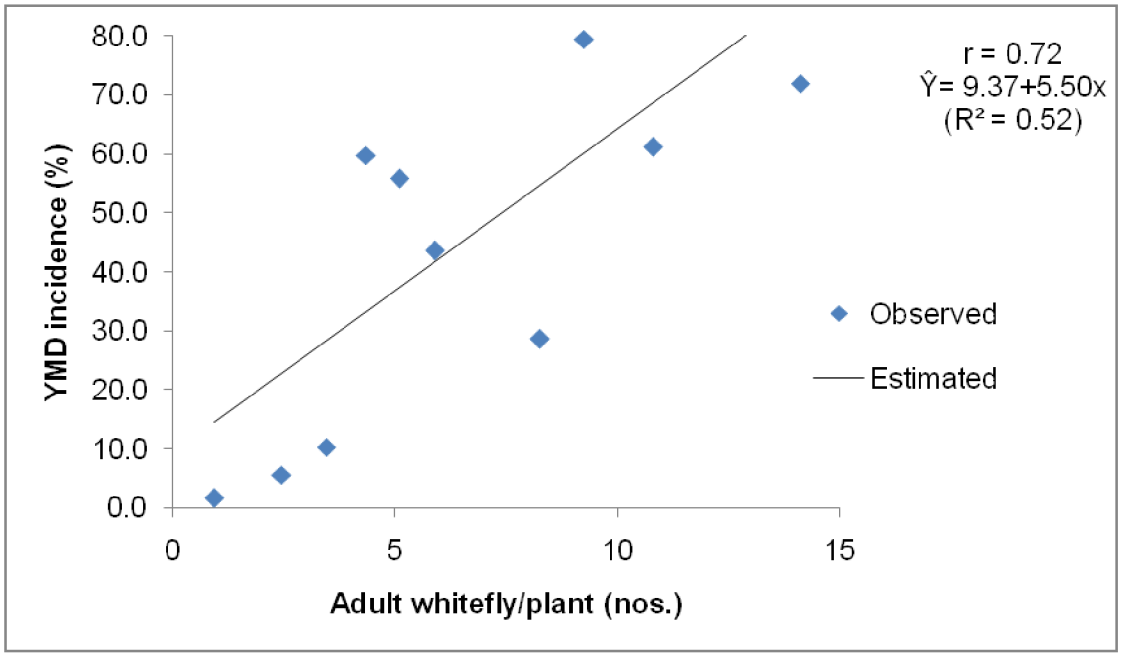

Fig. 39: Regression of YMD incidence on wind speed during *kharif* soybean (Pooled)

Preceding one week (P_1W):

Correlation studies between independent factors (*viz.* weather parameters, vector population and crop age) of disease incidence revealed that crop age exhibited significant positive association (r= 0.98) with disease incidence (Table 20).

The regression equation being:

$\hat{Y}$ = -15.66+1.24x (R^2 = 0.96)

From the above equation it may be expressed that with every unit increase in Max T, SS and crop age there was an increase of 1.24% disease incidence (Fig.36).

Correlation studies further revealed that Max T, SS, Evap and vector population exhibited positive correlation (r= 0.38, 0.50, 0.26 and 0.48, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Further, Min T, Morn and Even VP showed significant negative correlation (r= -0.83, -0.76 and -0.64, respectively) with disease incidence (Table 20).

The regression equation being:

$\hat{Y}$ =821.80-33.32x (R^2 = 0.69)

$\hat{Y}$ = 608.60-25.84x (R^2 = 0.58)

$\hat{Y}$ = 315.30-12.45x (R^2 = 0.40)

The above equations express that with every unit increase in Min T, Morn and Even VP there was a decrease of 33.32 (Fig. 37), 25.84 and 12.45% disease incidence.

While, Morn and Even RH, WS and RF exhibited negative correlation (r= -0.39, -0.56, -0.50 and -0.40, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Preceding two week (P_2W):

Further, correlation studies computed between independent factors (*viz.* weather parameters, vector population and crop age) preceding two week of YMD incidence revealed that vector population and crop age exhibited significant positive association (r= 0.72 and 0.98, respectively) with disease incidence (Table 20).

The regression equations being:

$\hat{Y}$ = - 9.37+5.50x (R^2 = 0.52)

$\hat{Y}$ = - 6.95+1.25x (R^2 = 0.96)

The above equations express that with every unit increase in vector population and crop age there was an increase of 5.50 and 1.25% disease incidence (Fig. 39 and 36, respectively).

Correlation studies further showed that Max T, SS and Evap exhibited positive correlation (r= 0.30, 0.47 and 0.41, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Further, Min T showed significant negative correlation (r= -0.71) with disease incidence (Table 20).

The regression equation being:

$\hat{Y}$ = 1004-40.86x (R^2 = 0.51)

The above equation expresses that with every unit increase in Morn RH and SS there was a decrease of 40.86% disease incidence.

While Morn and Even RH, WS, Morn and Even VP and RF exhibited negative correlation (r= -0.42, -0.49, -0.51, -0.58, -0.51 and -0.53, respectively) with disease incidence, but statistically found to be non-significant (Table 20).

Multiple regression:

R^2 obtained by computation of multiple regression equations between significant independent factors (x) of same week, prior to one and two weeks of YMD infection showed that the abiotic factors, vector population and crop age were responsible for influencing the disease incidence to the tune of 98%, 99% and 96%, respectively (Table 21).

3.2. To study the presence of MYMIV in whitefly and soybean plant through molecular technique

In order to understand the relationship between viruliferous whiteflies and disease expansion in the soybean host plant, the natural adult whiteflies and soybean leaf samples were collected from the soybean experimental field during three consecutive seasons *viz. rabi*, summer and *kharif*. A total of 20 adult whitefly and leaf samples were collected from 7 days old crop (DOC) and repeated at weekly intervals for the detection of MYMIV which was carried out by using specific primers *i.e.* Coat protein CP-(DNA-A) and DNA-B through PCR technique in the Department of Entomology, College of Agriculture, JNKVV, Jabalpur. In PCR assay, the positive results obtained with primers *i.e.* CP (DNA-A) and DNA-B having desired size amplicons *i.e.* 750bp and 541bp, respectively, which produced conspicuous bands were scored.

3.2.1 Post *Kharif/ Rabi* season

3.2.1. First year (2014-15)

3.2.1.a. Whitefly (*Bemisia tabaci*)

Perusal of the data presented in Table 22 showed that the detection results of MYMIV-CP (DNA-A) and DNA-B were found to be negative in the vector samples collected from 7 (Plate 13), 14, and 21 DOC. However, DNA-A and B were first detected in the whitefly samples collected from 28 and 35 DOC, respectively. DNA-A and B detected in the samples, ranged from 0 to 100% and 20 to 100%, respectively.

After the first detection of DNA-A and B in the samples, their presence gradually increased, with slight fluctuations observed in the samples collected from 42, 56 and 91 DOC. However, both the DNA's registered their presence upto the maturity of the crop (119 DOC). Analysis of the vector samples collected from 119 DOC (Plate 14) were found to be 100% viruliferous, as is evident by the presence of MYMIV in all the samples.

3.2.1.b. Leaf samples

Perusal of the data in Table 22 showed that the detection results of MYMIV DNA-A and B were found to be negative in the leaf samples collected from 7, 14, 21, 35 and 42 DOC. However, DNA-A and B were first detected in the leaf samples of 49 DOC, and 25% (Plate 15) samples showed their

presence which increased suddenly in the next week *i.e.* 56 DOC, and all the samples attained 100% infection.

3.2.1. 1 Second year (2015-16)

3.2.1.1. a. Whitefly

Perusal of the data in Table 22 showed that the detection results of DNA-A and B were found to be negative in the vector samples collected from 7 and 14 DOC. However, DNA-A and B were first detected in the whitefly samples collected from 21 and 28 DOC, respectively. DNA-A and B detected in the samples ranged from 20 to 90% and 20 to 100%, respectively.

After the first detection of DNA-A and B in the samples, their presence gradually increased, with slight fluctuations observed in the samples collected from 28, 70 and 91 DOC. However, both the DNA's registered their presence in the vectors upto the maturity of the crop (105 DOC). Analysis of the vector samples collected from 105 DOC, were found to be 80 and 100% positive with DNA-A and B, respectively.

3.2.1.1. b. Leaf samples

Perusal of the data in Table 22 showed that the detection results of DNA-A and B were found to be negative in the samples collected from 7, 14 and 28 DOC. However, DNA-A and B were first detected in the leaf samples of 35 DOC, and 10% samples showed their presence which increased suddenly in the next two weeks *i.e.* 49 DOC, and all the samples attained 100% infection.

3.2.2. Summer season:

3.2.2.1 First year (2015-16)

3.2.2.1.a. Whitefly (*B. tabaci*)

Perusal of the data presented in Table 22 showed that the detection results of DNA-A and B were found to be negative in the vector samples collected from 7 DOC. However, DNA-A and B were first detected in the whitefly samples collected from 14 DOC. DNA-A and B detected in the samples ranged from 25 to 95% and 30 to 90%, respectively.

After the first detection of DNA-A and B in the samples, their presence gradually increased, with slight fluctuations observed in the samples collected from 21 and 42 DOC. However, both the DNA's registered their presence upto the maturity of the crop (70 DOC). Analysis of the vector samples collected

from 70 DOC, were found to be 85 and 90% positive with DNA-A and B, respectively.

3.2.2.1. b. Leaf samples

Perusal of the data in Table 22 showed that the detection results of DNA-A and B were found to be negative in the leaf samples collected from 7 DOC. However, DNA-A and B were first detected in the leaf samples of 14 DOC and 20% samples showed their presence which increased suddenly in the next two weeks *i.e.* 28 DOC, and all the samples attained 100% MYMIV infection.

3.2.2.1.1 Second year (2016-17)

3.2.2.1.1.a. Whitefly (*B. tabaci*)

Perusal of the data presented in Table 22 showed that the detection results of DNA-A and B were found to be negative in the vector samples collected from 7 DOC. However, DNA-A and B were first detected in the whitefly samples collected from 14 DOC. DNA-A and B detected in the samples ranged from 15 to 85% and 10 to 95%, respectively.

After the first detection of DNA-A and B in the samples, their presence gradually increased with slight fluctuations, observed in the samples collected from 28, 70 and 63 DOC. However, both the DNA's registered their presence upto the maturity of the crop (91 DOC). Analysis of the vector samples collected from 90 DOC, were found to be 70 and 85% viruliferous with DNA-A and B, respectively.

3.2.2.1.1. b. Leaf samples

The data presented in Table 22 showed that the detection results of DNA-A and B were found to be negative in the leaf samples collected from 7 DOC. However, DNA-A and B were first detected in the leaf samples of 14 DOC, and 25% samples showed their presence, which increased gradually, and at 35 DOC all the samples attained 100% MYMIV infection.

3.2.3. Kharif season:

3.2.3.1 First year (2015-16)

3.2.3.1.a. Whitefly (*B. tabaci*)

The data presented in Table 22 showed that the detection results of DNA-A and B were first detected in the whitefly samples collected from 7 DOC. DNA-A and B detected in the samples ranged from 40 to 90% and 60 to

100%, respectively. After the first detection of DNA-A and B in the samples, their presence gradually increased with slight fluctuations observed in the samples collected from 49 and 56 DOC. However, both the DNA's registered their presence in the vectors upto the maturity of the crop (91 DOC). Analysis of the vector samples collected from 91 DOC, were found to be 90 and 100% viruliferous with DNA-A and B, respectively.

3.2.3.1. b. Leaf samples

Perusal of the data in Table 22 showed that the detection results of DNA-A and B were found to be negative in the leaf samples collected from 7 DOC. However, DNA-A and B were first detected in the leaf samples of 14 DOC and 40% samples showed their presence which increased suddenly in the next week *i.e.*21 DOC, and all the samples attained 100% MYMIV infection (Plate 16).

3.2.3.1.1 Second year (2016-17)

3.2.3.1.1.a. Whitefly (*B. tabaci*)

Perusal of the data presented in Table 22 showed that the detection results of DNA-A and B were first detected in the vector samples collected on 7 DOC. DNA-A and B detected in the samples ranged from 20 to 90% and 25 to 100%, respectively.

After the first detection of DNA-A and B in the samples, their presence gradually increased with slight fluctuations observed in the samples collected from 21, 35, 49 and 56 DOC. However, both the DNA's registered their presence upto the maturity of the crop (91 DOC). Analysis of the vector samples collected from 91 DOC, were found to be 60 and 100% viruliferous with DNA-A and B, respectively.

3.2.3.1.1. b. Leaf samples

Perusal of the data in Table 22 showed that the detection results of DNA-A and B were found to be negative in the samples collected from 7 and 14 DOC. However, DNA-A and B were first detected in the leaf samples of 21 and 28 DOC *i.e.* 20% and 90% (Plate 17) samples showed their presence, which increased suddenly in the next two weeks *i.e.* 35 DOC, and all the samples attained 100% MYMIV infection.

Table 22: Status of soybean leaves and whitefly tested for the detection of MYMIV at Jabalpur during *rabi*, summer and *kharif* 2014-15 and 2015-16

Crop age (days)	Samples positive with MYMIV specific primers (%)																							
	Rabi								Summer								Kharif							
	2014-15				2015-16				2015-16				2016-17				2015-16				2016-17			
	Whitefly		Leaves		Whitefly		Leaves		Whitefly		Leaves		Whitefly		Leaves		Whitefly		Leaves		Whitefly		Leaves	
	DNA		DNA		DNA		DNA		DNA		DNA		DNA		DNA		DNA		DNA		DNA		DNA	
	A*	B#	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	55	75	0	0	40	40	0	0
14	0	0	0	0	0	0	0	0	95	85	20	20	15	40	25	25	80	60	40	40	85	90	0	0
21	0	0	0	0	20	0	0	0	25	70	45	50	50	10	40	50	60	85	100	100	35	35	20	20
28	35	0	0	0	40	75	0	0	65	40	100	100	30	50	60	65	8	75	-	-	65	65	90	90
35	60	90	0	0	60	70	10	10	55	55	-	-	55	60	100	100	90	95	-	-	40	90	100	100
42	20	20	0	0	75	95	65	65	30	30	-	-	85	95	-	-	85	80	-	-	50	95	-	-
49	35	35	25	25	65	75	100	100	55	75	-	-	85	75	-	-	55	70	-	-	45	60	-	-
56	20	20	100	100	90	65	-	-	90	80	-	-	70	65	-	-	40	95	-	-	20	25	-	-
63	50	45	-	-	90	80	-	-	90	80	-	-	45	40	-	-	60	95	-	-	50	90	-	-
70	25	25	-	-	40	80	-	-	85	90	-	-	20	60	-	-	75	95	-	-	70	75	-	-
77	95	85	-	-	85	95	-	-	-	-	-	-	45	75	-	-	55	100	-	-	80	80	-	-
84	20	55	-	-	80	50	-	-	-	-	-	-	55	90	-	-	80	100	-	-	90	80	-	-
91	0	40	-	-	55	20	-	-	-	-	-	-	70	85	-	-	90	100	-	-	60	100	-	-
98	50	50	-	-	80	85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
105	85	80	-	-	80	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
112	50	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
119	100	100																						

A*=DNA-A, B#=DNA-B

3.3. The virus (MYMIV)-vector (*B. tabaci*) relationship in soybean in insect proof net house

3.3.1. Acquisition access period (AAP)

3.3.1.a. First year (2015-16)

The data on effect of various acquisition feeding period by adult female whitefly on transmission and incubation period of MYMIV in soybean plants after 24 h inoculation period are presented in Table 23. Perusal of the data revealed that the differences in the transmission of MYMIV infection and disease symptom expression period among different acquisition feeding periods were significant. The non viruliferous whiteflies required a minimum acquisition feeding period of 0.5 h (T_1) to become viruliferous which transmitted 10% YMD infection in plants and the disease symptoms first appeared in 26.1 days. As the acquisition feeding period increased, there was a gradual increase in the infection rate with decrease in the disease symptom expression period, but treatments T_1 and T_2 were at par with each other. However, at 12 h (T_5) of acquisition feeding period, 100% disease infection was observed and the disease symptoms appeared in 20.7 days. Moreover the disease symptom expression period reduced and it was 19.4 days when the acquisition feeding period was 24 h (T_6), but was at par with T_5.

Correlation studies revealed that AAP exhibited significant positive (r = 0.82) and negative association (r=-0.92) with MYMIV infection and disease symptom expression period, respectively.

The regression equations computed were:

$\hat{Y} = 34.98+3.44x$ ($R^2=0.68$)

$\hat{Y} = 25.25 -0.34x$ ($R^2 = 0.85$)

From the above equations it may be expressed that with every unit increase in AAP, there was an increase of 3.44% MYMIV infection and decrease of 0.34 day in the disease symptom expression period, respectively.

Table 23: Effect of acquisition access periods (AAP) by adult female whitefly, *B. tabaci* on transmission and incubation period of MYMIV in soybean plants after 24 h inoculation access period

Treatment Code	AAP (h)	MYMIV infected plants #					Disease symptom expression period (days)		
		2015-16		2016-17		Pooled			
		Nos.	Transmission (%)	Nos.	Transmission (%)	Transmission (%)	2015-16	2016-17	Pooled
T_1	0.5	1	10 (12.70)	2	20 (21.34)	15 (19.46)	26.1	26.1	26.1
T_2	1	3	30 (29.99)	1	10 (12.70)	20 (30.20)	25.1	25.5	25.3
T_3	3	5	50 (47.28)	4	40 (38.63)	45 (50.68)	23.0	22.7	22.9
T_4	6	8	80 (73.21)	7	70 (64.57)	75 (72.46)	22.8	22.3	22.6
T_5	12	10	100 (90.50)	10	100 (90.50)	100 (90.50)	20.7	20.5	20.6
T_6	24	10	100 (90.50)	10	100 (90.50)	100 (90.50)	19.4	18.3	18.9
SEm±		-	9.91	-	9.84	6.70	0.69	0.65	0.60
CD at 5%		-	28.11	-	27.91	19.00	2.06	1.93	1.70

Plants inoculated=10 @10 adult female whiteflies/plant

() Figures in parentheses are arcsin transformed values

3.3.1. b. Second year (2016-17)

Perusal of the data presented in Table 23 revealed that the differences in the transmission of MYMIV infection and disease symptom expression period among different acquisition feeding periods were significant. The trend was similar as observed in the first year. The non viruliferous whiteflies required a minimum acquisition feeding period of 0.5 h (T_1) to become viruliferous which transmitted 20% YMD infection in plants and the disease symptoms first appeared in 26.1 days. As the acquisition feeding period increased, there was a gradual increase in the infection rate with decrease in the disease symptom expression period, but treatments T_1 and T_2 were statistically at par with each other. However, at 12 h (T_5) of acquisition feeding period, 100% disease infection was observed and the disease symptoms appeared in 20.5 days and it reduced to 18.3 days when the acquisition feeding period was 24 h (T_6), but they did not differ significantly from each other.

Correlation studies revealed that AAP exhibited significant positive (r = 0.85) association with MYMIV infection.

The regression equation computed was:

$$\hat{Y} = 24.49+3.93x \ (R^2=0.73)$$

From the above equation it may be expressed that with every unit increase in AAP, there was an increase of 3.93% MYMIV infection.

Further, AAP showed positive correlation (r=0.19) with disease symptom expression period, but statistically found to be non significant.

3.3.1. c. Pooled data

The pooled data presented in Table 23 and Fig. 40 revealed that the differences in the transmission of MYMIV infection and disease symptom expression period among different acquisition feeding periods were significant. The non viruliferous whiteflies required a minimum acquisition feeding period of 0.5 h (T_1) to become viruliferous which transmitted 15% YMD infection in plants and the disease symptoms first appeared in 26.1 days. As the acquisition feeding period increased, there was a gradual increase in the infection rate with decrease in the disease symptom expression period, but treatments T_1 and T_2 were statistically at par with each other. However, at 12 h (T_5) of acquisition feeding period, 100% disease

infection was observed and the disease symptoms appeared in 20.6 days which further reduced to 18.9 days at 24 h AAP, but non significant differences were observed between them.

Correlation studies revealed that AAP exhibited significant positive (r = 0.85) and negative association (r=-0.92) with MYMIV infection and disease symptom expression period, respectively.

The regression equations computed were:

$\hat{Y} = 31.26+3.60x$ ($R^2=0.72$)

$\hat{Y} = 24.90-0.28x$ ($R^2 = 0.85$)

From the above equations it may be expressed that with every unit increase in AAP, there was an increase of 3.60% MYMIV infection and decrease in the disease symptom expression period by 0.28 day, respectively (Fig. 41).

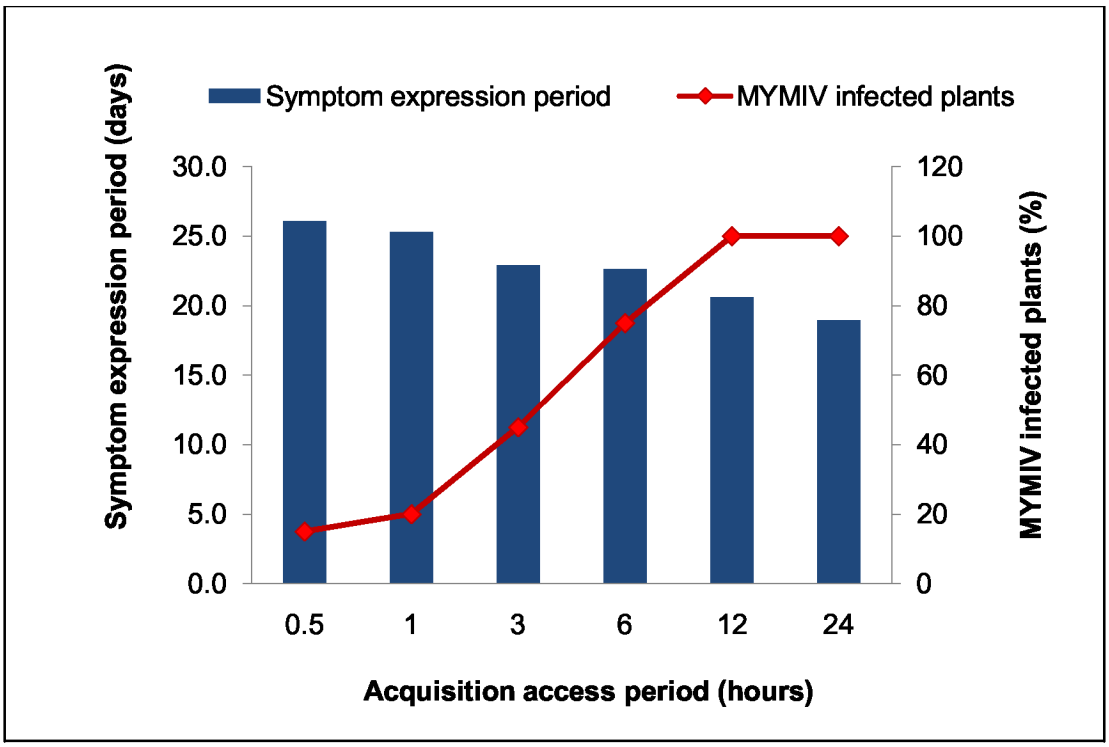

Fig. 40: Effect of various acquisition access periods by adult female whitefly B. tabaci on transmission and disease expression period of MYMIV in soybean plants after 24 h inoculation access period

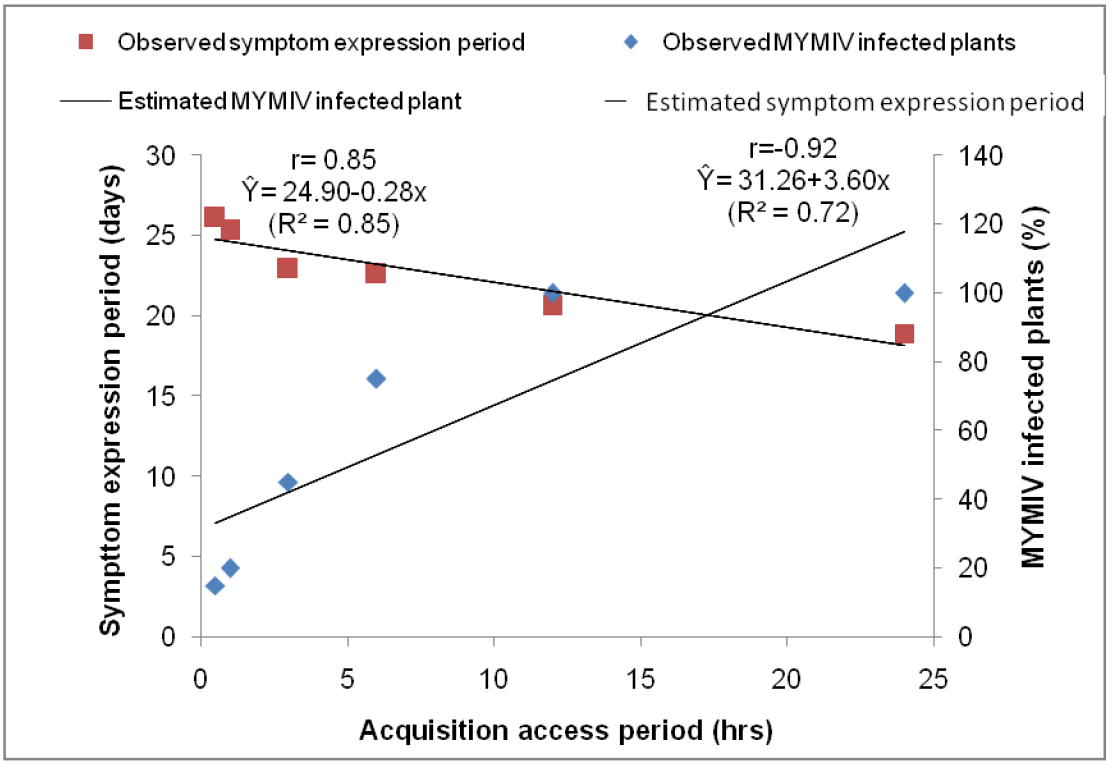

Fig. 41: Regression of acquisition access period on symptom expression period and MYMIV infected plants in soybean plants

3.3.2. Inoculation access period (IAP)

3.3.2. a. First year (2015-16)

The data on effect of various IAP by viruliferous adult female whitefly on transmission and incubation period of MYMIV in soybean plants after 24 h acquisition feeding period are presented in Table 24. From the Table, it is evident that the differences in the transmission of MYMIV infection and the disease symptom expression period among different inoculation periods were significant. The viruliferous female adult whiteflies required a minimum inoculation period of 1 h (T_1) and transmitted 10% YMD infection in the plants and the disease symptoms appeared in 23.3 days. The inoculation period was found to be directly proportional to the infection rate and inversely proportional to the disease symptom expression period, but treatments T_1 and T_2 were statistically at par with each other. However, at 18 h (T_5) of inoculation period, 100% disease infection was observed and the disease symptoms appeared in 18.1 days. Moreover, at maximum inoculation period of 24 h (T_6), the disease symptom expression period was minimum (15.8 days), but was at par with T_5.

Correlation studies showed that IAP exhibited significant positive (r = 0.92) and negative correlation (r=-0.92) with MYMIV infection and disease symptom expression period, respectively.

The regression equations were:

$\hat{Y}$ = 25.98+3.66x (R^2=0.86)

$\hat{Y}$ = 24.26 -0.05x (R^2 = 0.86)

From the above equations it may be expressed that with every unit increase in IAP, there was an increase of 3.66% MYMIV infection and decrease of 0.05 day in the disease symptom expression period, respectively.

3.3.2.b. Second year (2016-17)

Perusal of the data presented in Table 24 showed that the differences in the transmission of MYMIV infection and disease symptom expression period among different inoculation periods were significant. The trend was similar as observed in the first year of experimentation. The viruliferous adult female whiteflies required a minimum inoculation period of 1 h (T_1) to transmit 10% YMD infection in the plants and the disease symptoms appeared in 24.7 days. As the inoculation period increased there was a gradual increase in the infection rate and simultaneously the disease symptom expression period decreased, but the treatments T_1 and T_2 were statistically at par with each other. However, at 18 h (T_5) of inoculation period, 100% disease infection was observed and the disease symptoms appeared in 16.9 days, while it was 15.7 days when the inoculation period was 24 h (T_6), but they did not differ significantly from each other.

Correlation studies revealed that IAP exhibited significant positive (r = 0.92) and negative association (r=-0.92) with MYMIV infection and disease symptom expression period, respectively.

The regression equations computed were:

$\hat{Y}$ = 17.06+4.18x (R^2=0.86)

$\hat{Y}$ = 24.61-0.05x (R^2 = 0.92)

From the above equations it may be expressed that with every unit increase in IAP, there was an increase of 4.18% MYMIV infection and decrease of 0.05 day in the disease symptom expression period, respectively.

3.3.2. c. Pooled data

The pooled data presented in Table 24 and Fig. 42 revealed that the differences in the transmission of MYMIV infection and the disease symptom expression period among different inoculation periods were significant. The viruliferous adult female whiteflies required a minimum inoculation period of 1 h (T_1) to transmit 10% YMD infection in the plants and the first disease symptoms appeared in 24 days. Inoculation period was found to be directly proportional to the infection rate and inversely proportional to the disease symptom expression period, but treatments T_1 and T_2 were significantly at par with each other. However, at 18 h (T_5) of inoculation period, 100% disease infection was observed and the disease symptoms appeared in 17.5 days, which reduced to 15.8 days at 24 h IAP (T_6), but non significant differences were observed between them.

Correlation studies revealed that IAP exhibited significant positive (r = 0.93) and negative association (r=-0.98) with MYMIV infection and disease symptom expression period, respectively.

The regression equations were:

$\hat{Y} = 21.52+3.92x$ ($R^2=0.87$)

$\hat{Y} = 23.57- 0.23x$ ($R^2 = 0.97$)

From the above equations it may be expressed that with every unit increase in IAP, there was an increase of 3.92% MYMIV infection and decrease of 0.23 day in the disease symptom expression period, respectively (Fig. 43).

Table 24: Effect of inoculation access periods (IAP) by adult female whitefly, *B. tabaci* on transmission and incubation period of MYMIV in soybean plants after 24 h of acquisition access period

Treatment Code	IAP (h)	MYMIV infected plants #					Disease symptom expression period (days)		
		2015-16		2016-17		Pooled	2015-16	2016-17	Pooled
		Nos.	Transmission (%)	Nos.	Transmission (%)	Transmission (%)			
T_1	1	1	10 (12.70)	1	10 (12.70)	10 (12.70)	23.3	24.7	24.0
T_2	3	3	40 (38.63)	2	20 (21.34)	30 (29.59)	21.6	23.8	22.7
T_3	6	5	60 (55.92)	5	50 (47.28)	55 (51.40)	19.7	20.5	20.1
T_4	12	8	80 (73.21)	9	90 (81.86)	85 (77.33)	18.8	19.9	19.4
T_5	18	10	100 (90.50)	10	100 (90.50)	100 (90.50)	18.1	16.9	17.5
T_6	24	10	100 (90.50)	10	100 (90.50)	100 (90.50)	15.8	15.7	15.8
SEm±		-	10.05	-	9.04	8.92	0.62	0.92	0.61
CD at 5%		-	28.50	-	25.62	25.30	1.75	2.61	1.72

Plants inoculated=10 @10 adult female whiteflies/plant

() Figures in parentheses are arcsin transformed values

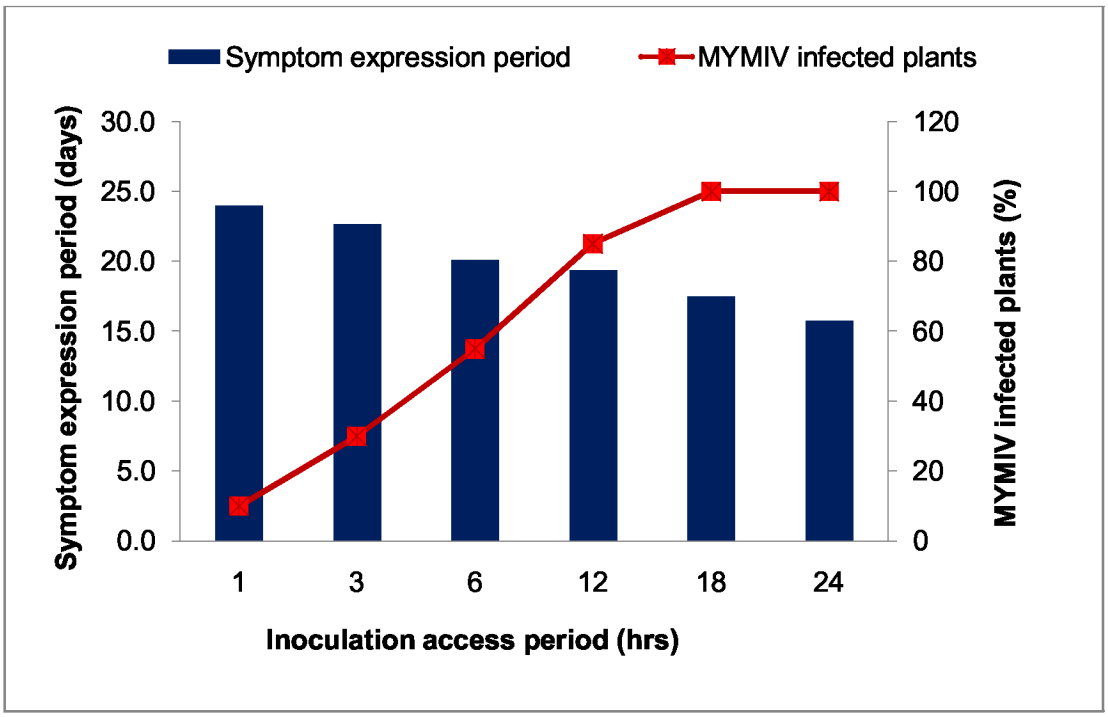

Fig.42: Effect of various inoculation access periods by adult female whitefly *B. tabaci* on transmission and symptom expression period of MYMIV in soybean plants after 24 h of acquisition access period

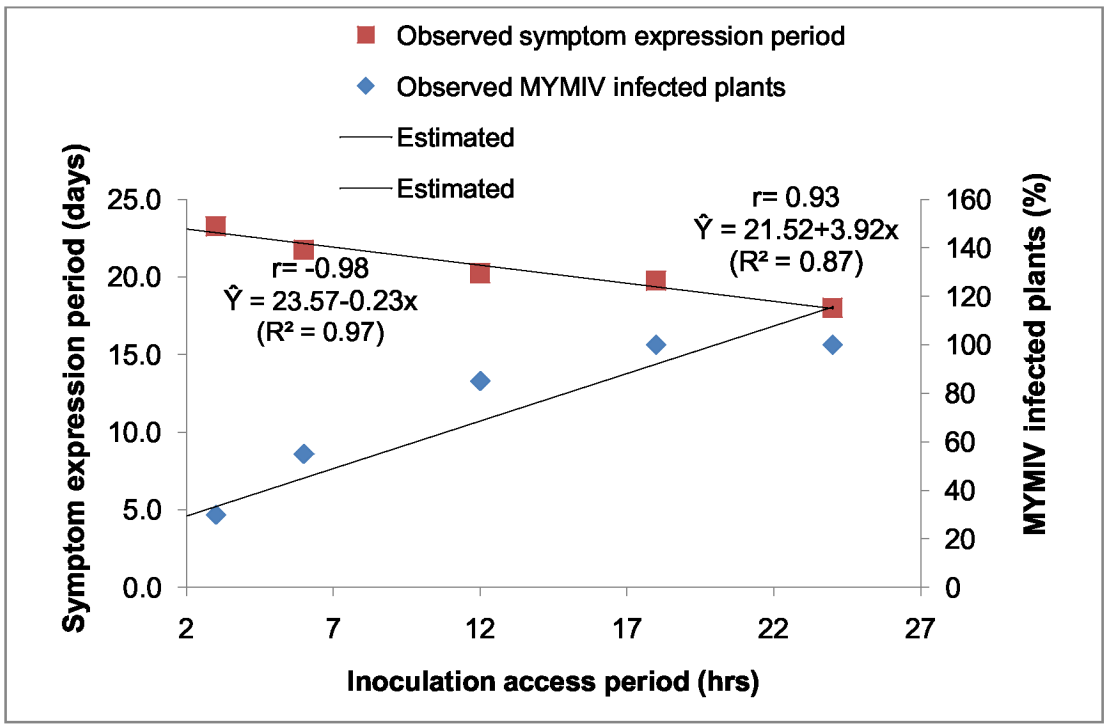

Fig. 43: Regression of inoculation access period on MYMIV infected plants symptom expression period in soybean plants

3.3.3. Effect of vector population

3.3.3.a. First year (2015-16)

The data on determination of threshold number of viruliferous adult female whiteflies required for MYMIV transmission after exposure for 24 h of AAP and IAP are presented in Table 25. From the Table, it is evident that the differences in the transmission of MYMIV infection and disease symptom expression period among different population density of viruliferous whiteflies/ plant were found to be statistically significant. A single viruliferous adult female whitefly (T_1) per plant was capable of transmitting 20% YMD infection in the plants and the disease symptoms appeared in 27.4 days. The viruliferous whitefly population density was found to be directly proportional to the infection rate and inversely proportional to the disease symptom expression period. Significantly lowest YMD infection rate (20%) was observed in treatment T_1 followed by T_2 (50%), but both were at par with each other. However, at population density of 10 viruliferous adult whiteflies/ plant (T_4), 100% disease infection was observed and the symptoms appeared in 19 days. Moreover, the disease symptom expression period reduced, and it was 14.1 and 13 days when the vector population was 15 and 20 viruliferous whiteflies/ plant (T_5 and T_6, respectively), but they did not differ significantly from each other.

Computation of correlation studies revealed that viruliferous whitefly/plant showed significant positive (r = 0.86) and negative association (r=-0.95) with MYMIV infection and disease symptom expression period, respectively.

The regression equations were:

$\hat{Y} = 38.51+3.88x$ ($R^2=0.74$)

$\hat{Y} = 25.86-0.61x$ ($R^2 = 0.88$)

From the above equations it may be expressed that with every unit increase in viruliferous whitefly/plant, there was an increase of 3.88% MYMIV infection and decrease of 0.61 day in the disease symptom expression period.

3.3.3.b. Second year (2016-17)

Perusal of the data presented in Table 25 revealed that the differences in the transmission of MYMIV infection and disease symptom expression period among different population of viruliferous whiteflies/ plant were

significant. A single viruliferous adult female whitefly (T_1) transmitted 10% YMD infection in the plants and the disease symptoms appeared in 27.2 days. The trend was similar as observed in the first year. As the number of viruliferous whitefly/ plant increased, there was a gradual increase in the infection rate with decrease in the disease symptom expression period. Significant difference was observed in YMD infection between the treatments T_1 (10%) and T_2 (30%). However, at population density of 10 viruliferous adult whiteflies/ plant (T_4), 100% disease infection was observed and the disease symptoms appeared in 17.8 days. Moreover, the disease symptom expression period reduced and it was 13.7 and 12.9 days when the vector population was 15 and 20 viruliferous whiteflies/ plant (T_5 and T_6, respectively), but both were at par with each other. Correlation studies showed that viruliferous whitefly/plant exhibited significant positive (r= 0.88) and negative correlation (r= -0.93) with MYMIV infection and the disease symptom expression period, respectively.

The regression equations were:

$\hat{Y} = 23.96+4.74x$ ($R^2=0.77$)

$\hat{Y} = 25.82 -0.58x$ ($R^2 = 0.87$)

From the above equations it may be expressed that with every unit increase in IAP, there was an increase of 4.74% MYMIV infection and decrease of 0.58 day in the disease symptom expression period.

3.3.3. c. Pooled data

Perusal of the pooled data presented in Table 25 and Fig. 44 revealed that the differences in the transmission of MYMIV infection and disease symptom expression period among different population density of viruliferous whiteflies/ plant were significant. A single viruliferous adult female whitefly (T_1) transmitted 15% YMD infection in the plants and the disease symptom appeared in 27.3 days. Vector population density was found to be directly and indirectly proportional to the MYMIV infection rate and the disease symptom expression period, respectively. Significant difference was observed in YMD infection between the treatments T_1 (15%) and T_2 (40%). However, at population density of 10 viruliferous adult whiteflies/ plant (T_4), 100% disease infection was observed and the disease symptoms appeared in 18.4 days.

Table 25: Influence of population density of viruliferous adult female whiteflies, *B. tabaci* on transmission of MYMIV in soybean plants after 24 h of acquisition and inoculation access periods

Treatment Code	Viruliferous whitefly / plant	MYMIV infected plants #					Disease symptom expression period (days)		
		2015-16		2016-17		Pooled			
		Nos.	Transmission (%)	Nos.	Transmission (%)	Transmission (%)	2015-16	2016-17	Pooled
T_1	1	2	20(21.34)	1	10 (12.70)	15 (16.42)	27.4	27.2	27.3
T_2	3	5	50 (47.28)	3	30 (29.99)	40 (37.43)	22.9	25.9	24.4
T_3	5	7	70 (64.57)	6	60 (55.92)	65 (60.04)	20.6	20.9	20.8
T_4	10	10	100 (90.50)	10	100 (90.50)	100 (90.50)	19.0	17.8	18.4
T_5	15	10	100 (90.50)	10	100 (90.50)	100 (90.50)	14.1	13.7	13.9
T_6	20	10	100 (90.50)	10	100 (90.50)	100 (90.50)	13.0	12.9	13.0
SEm±		-	9.26	-	8.64	6.84	0.64	0.86	0.57
CD at 5%		-	26.26	-	24.51	19.40	1.82	2.43	1.62

Healthy plants exposed=10

() Figures in parentheses are arcsin transformed values

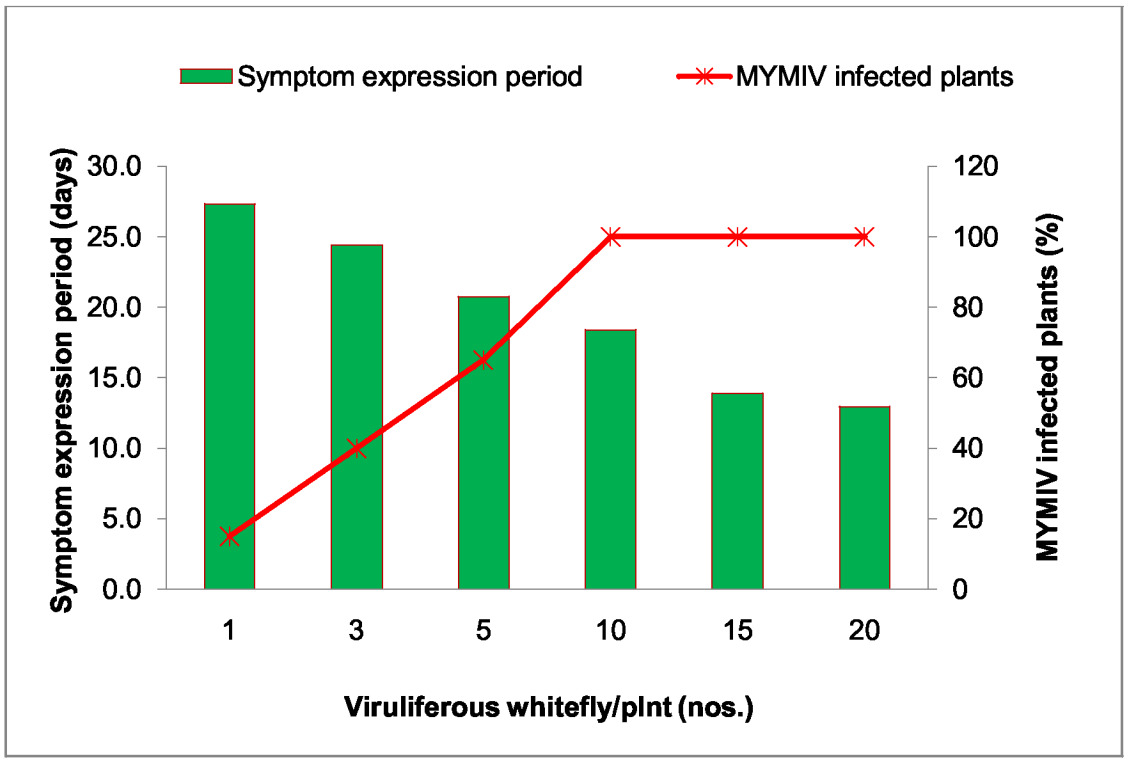

Fig. 44: Influence of population density of viruliferous adult female whiteflies *B. tabaci* on transmission of MYMIV in soybean plants after 24 h of acquisition and inoculation access period

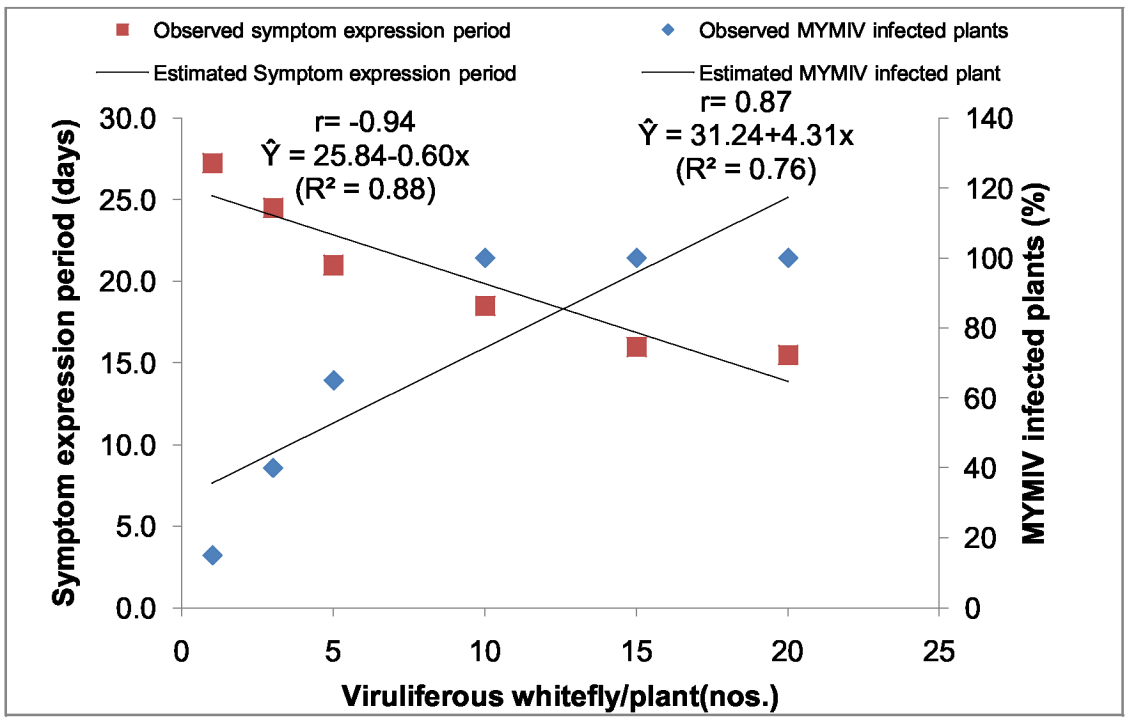

Fig. 45: Regression of population density of viruliferous adult female whiteflies on MYMIV infected plants and symptom expression period in soybean plants

Moreover, the disease symptom expression period reduced and it was 13.9 and 13 days when the vector population was 15 and 20 viruliferous whiteflies/ plant (T_5 and T_6, respectively), but they did not differ significantly from each other.

Correlation studies revealed that viruliferous whitefly/plant exhibited significant positive correlation (r = 0.87) with MYMIV infection.

The regression equation was:

$\hat{Y} = 31.24+4.31x$ ($R^2=0.76$)

From the above equation it may be expressed that with every unit increase in viruliferous whitefly/plant, there was an increase of 4.31% MYMIV infection (Fig. 45).

Further, viruliferous whitefly/plant exhibited significant negative correlation (r=-0.94) with the disease symptom expression period.

The regression equation was:

$\hat{Y} = 25.84 -0.60x$ ($R^2 = 0.88$)

From the above equation it may be expressed that with every unit increase in viruliferous whitefly/plant, there was a decrease of 0.60 day in the disease symptom expression period (Fig. 45).

3.3.4. Retention period of virus in the vector:

For determining the retention period of the virus in the vector, adult female whiteflies were allowed 24 h of AAP on MYMIV-infected soybean plants and then a single viruliferous female whitefly was transferred serially on a healthy soybean seedling at one day interval and this process continued, till the death of the vector.

3.3.4.a. First year (2015-16)

The data presented in Table 26 and showed that the vector started transmitting the virus from 1st day onward and the maximum retention period was observed upto 14th day as is evident by the infected plants. Further, maximum disease infection was recorded on 2nd day, thereafter, there was a decline in the intensity of infection with slight fluctuations on the 5th, 7th and 11th day of serial transfer. The mortality of the whitefly started from 11th day and it gradually increased and maximum mortality was recorded on 14th day and thereafter it declined and was observed upto 16th day of serial transfer.

Correlation studies revealed that serial transfer days exhibited significant

negative correlation (r = -0. 72) with MYMIV infection.

The regression equation was:

$\hat{Y}$ = 94.61-3.472x (R^2 = 0.53)

From the above equation it may be expressed that with every unit increase in the serial transfer day, there was a decrease of 3.47% MYMIV infection.

3.3.4.b. Second year (2016-17)

The data presented in Table 26 revealed that the vector started transmitting the virus from 1st day of serial transfer and the maximum retention period was observed upto 15th day as is evident by the infected test plants. The trend was similar as observed in the first year experimentation. Further, maximum disease infection was observed on 2nd day, thereafter, the intensity of the disease infection gradually declined with slight fluctuations on the 5th and 11th day of serial transfer. The mortality of the whitefly started from 12th day onwards the trend gradually increased and maximum mortality was recorded on 16th day of serial transfer.

Correlation studies showed that serial transfer days expressed significant negative (r = -0.70) correlation with MYMIV infection.

The regression equation was:

$\hat{Y}$ = =88.76-3.17x (R^2 = 0.49)

From the above equation it may be expressed that with every unit increase in serial transfer day, there was a decrease of 3.17% MYMIV infection.

3.3.4. c. Pooled data

Perusal of the pooled data presented in Table 26 and 27 and Fig. 46 revealed that the vector started transmitting the virus from 1st day of serial transfer and the maximum retention period was observed upto 15th day. Moreover, maximum disease infection was observed on the 2nd day, thereafter, the disease infection gradually declined with slight fluctuations on the 5th and 11th day of serial transfer. Whereas, the mortality of the vectors started from 11th day and they attained maximum on 16th day of serial transfer.

Correlation studies revealed that serial transfer days exhibited significant negative impact (r = -0.76) on MYMIV infection.

Table 26: Retention period of MYMIV by single adult female whitefly *B. tabaci* after 24 h of acquisition and inoculation access periods

Code letter of adult female whitefly *B.tabaci* per plant	Serial transfer at 1 day interval																													
	2015-16																2016-17													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	+	+	-	+	+	+	+	+	+	-	+	+	+	+	D		+	-	+	+	+	+	-	+	+	+	+	+	-	D		
B	+	+	+	-	-	+	+	+	+	-	D						+	+	+	+	-	+	+	+	+	-	+	+	-	+	D	
C	+	+	+	+	+	+	+	-	+	+	+	+	+	D			+	+	-	-	+	-	+	+	-	-	-	+	+	D		
D	-	+	+	-	+	+	+	+	-	+	+	+	-	-	D		+	+	+	+	+	+	+	+	-	+	+	D				
E	+	+	+	+	+	+	+	-	+	+	+	-	+	D			-	+	+	+	+	-	+	-	+	+	+	+	+	+	D	
F	+	+	-	-	+	+	-	+	+	+	+	-	+	D			+	+	-	-	+	+	+	-	+	+	+	-	+	+	+	D
G	+	+	+	+	+	-	+	+	-	-	+	+	D				+	+	+	+	+	+	-	-	-	+	+	+	+	D		
H	+	+	+	+	+	+	+	-	+	+	-	+	D				-	+	+	-	+	-	+	+	+	-	+	+	+	D		
I	-	+	-	+	+	-	+	+	-	+	+	D					+	+	-	-	+	+	-	-	+	+	+	D				
J	+	+	+	-	+	+	+	+	-	-	-	+	+	+	-	D	+	+	+	+	-	+	-	+	+	+	-	-	+	D		

+ = Infection; - = No infection; D= Death of individual whitefly

Table 27: Retention period of MYMIV by a single adult female whitefly after 24 hrs of AAP and IAP

Serial transfer (days)	Infected plants (%)			Whitefly mortality (%)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
1	80	80	80	-	-	-
2	100	90	95	-	-	-
3	70	70	70	-	-	-
4	60	60	60	-	-	-
5	90	80	85	-	-	-
6	80	70	75	-	-	-
7	90	60	75	-	-	-
8	70	60	65	-	-	-
9	60	70	65	-	-	-
10	60	70	65	-	-	-
11	70	80	75	10	0	5
12	60	60	60	10	20	15
13	50	60	55	20	0	10
14	20	30	25	30	50	40
15	-	10	10	20	20	20
16	-	-	-	10	10	10

The regression equation was:

$\hat{Y}$ = =93.85-3.73x (R^2 = 0.59)

From the above equation it may be expressed that with every unit increase in serial transfer day, there was a decrease of 3.73% MYMIV infection (Fig. 47).

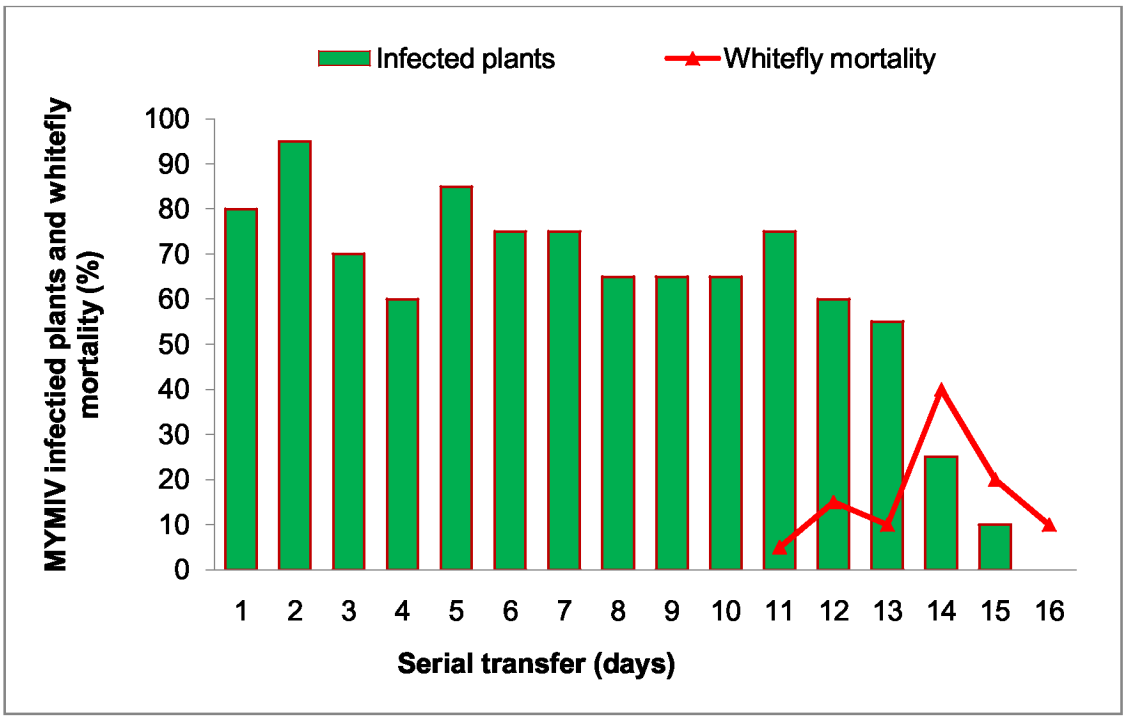

Fig. 46: Retention period of MYMIV by a single adult female whitefly *B. tabaci* after 24 h of AAP and IAP

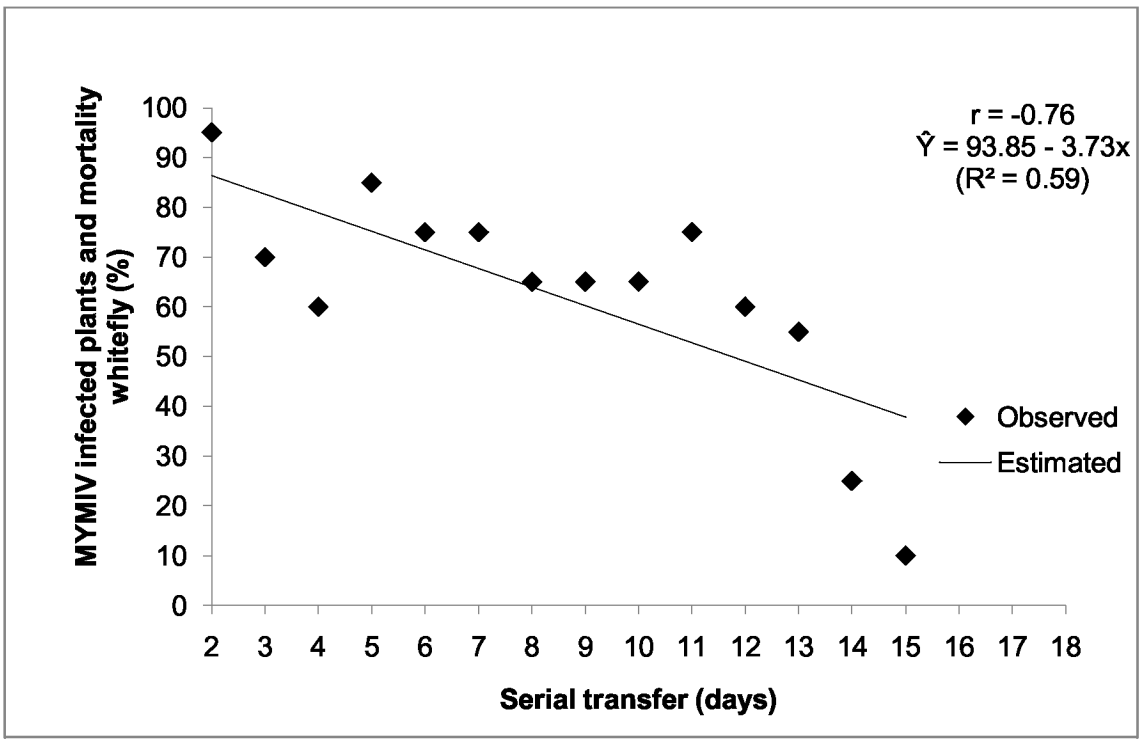

Fig. 47: Regression of serial transfer of whitefly on MYMIV infected plants and whitefly mortality.

DISCUSSION

The findings on "Studies on whitefly, *Bemisia tabaci* Genn., vector of mungbean yellow mosaic India virus with special reference to seasonal fluctuation and virus-vector relationship in soybean" have been discussed below:

5.1 To study the seasonal incidence of whitefly and yellow mosaic disease in soybean crop

5.1.1. Whitefly, *Bemisia tabaci* Genn. (Hemiptera: Aleyrodidae)

5.1.1.1 Post *Kharif / Rabi* season

During first and second year of study, the first appearance of whitefly on soybean was observed on 7 days old crop (DOC) *i.e.* 49th SW (*i.e.* 3rd to 9th December, 2014) and 1st SW (*i.e.* 1st to 7th January, 2016), respectively. Present findings are in conformity with the findings of Barfa (2007) and Chandrakumar et al. (2008), as they also reported its first incidence during 3rd and 4th week of December on tomato and brinjal, respectively.

In the present study whitefly was available upto the crop maturity stage and confirms the findings of Akbar et al. (2000) and Barfa (2007), as they also reported that whitefly was available upto the crop maturity stage in *rabi* soybean and tomato, respectively.

The overall mean population of whitefly recorded during the *rabi* season was 2.30 adult whiteflies/plant. The present findings are in agreement with the findings of Patel (2006), as he also reported 2.12 whiteflies/leaf on *rabi* mungbean. However the present findings are partially in accordance with the findings of Akbar et al. (2000) and Biswas (2013). They reported that the mean whitefly population on *rabi* soybean was of 0.21/leaf and 7.75/plant, respectively. The difference in the whitefly population may be attributed to the variation in the date of sowing, maturity period of the crop and the susceptibility status of the variety included in the studies.

During the first and second year of study two and three peaks were obtained when the crop age was 84, 112 (8th and 12th SW) and 35, 63 and 91 (5th, 9th and 13th) DOC, respectively. The present findings are in partial agreement with the findings of Patil (2006), Panduranga et al. (2011) and

Gopalaswamy et al. (2012), as they reported that whitefly attained a single peak on 51 DOC (2.12 whiteflies/plant) on *rabi* soybean, 40 DOC (2nd week of January) (9.55 whiteflies/5 plants) and 45 DOC (and 33.33 whiteflies/5 plants) on *rabi* mungbean and urdbean, respectively. Similarly, Chaudhuri et al. (2001) and Barfa (2007) reported that whitefly attained peak during first and second week of February on tomato, respectively.

During peak periods of whitefly, Max T, Min T, Morn RH, Even RH, WS, SS, Morn VP, Even VP, Evap and RF ranged between 22.2-32.5^{0}C, 8.4-13.0^{0}C, 76.5-91.5%, 25.5-51.0%, 2.6-3.5 km/hr, 6.8-9.9 hrs, 8.5-10.5 mm, 9.0-9.5 mm, 1.5-4.3 mm and 0.0-6.1 mm, respectively. Present findings are in agreement with the findings of Chaudhuri et al. (2001), as they also reported that during the peak periods Max T, Min T and Even RH were 29.20C, 13.40C and 87%, respectively with no rainfall.

The present findings indicated that high temperature, coupled with low rainfall were found to be favourable for the build-up of the pest population on *rabi* soybean (Biswas, 2013).

In the present study Max T exhibited significant positive influence on whitefly population. Similar findings have been reported by Patil (2006) on mungbean. However, it contradicts the findings of Chandrakumar et al. (2008) and Naik et al. (2009) on brinjal and Subba et al. (2017) on tomato, as they reported that Max T had negative association with whitefly population.

Further, Min T exhibited significant positive impact on whitefly population are in conformity with the findings of Naik et al. (2009), as they also reported that Min T had positive association with whitefly population on brinjal. On the contrary, Subba et al. (2017) reported that Min T had shown negative correlation with whitefly population on tomato, but statistically non-significant.

In the present investigation Evap and crop age showed significant positive impact on whitefly population.

Computation of multiple regression analysis with significant weather parameters and crop age showed that independent variables were responsible for about 74% (R^2 value) variation in the whitefly population.

Path analysis further revealed that Morn VP and Morn RH exhibited highest positive and negative direct effect on whitefly population, respectively and the residual effect computed was 0.2055, which indicated that the weather parameters and crop age included in the study were adequate as they exerted a major impact on the whitefly population.

5.1.1.2 Summer season

During first and second year of study in the summer season, the first appearance of whitefly on soybean was observed on 7 DOC *i.e.* 14th SW (2nd to 8th April, 2015) and 10th SW (5th to 11th March, 2016), respectively and were available up to the crop maturity stage (23rd SW and 22nd SW, respectively). The present findings confirms the findings of Dar et al. (2002), Ahirwar (2008) and Sharma et al. (2013). They also reported that the first appearance of whitefly was recorded during 3rd week of April, both on summer mungbean and urdbean, 3rd week of March on summer mungbean and 2nd week of April on tomato, respectively, and the pest was available upto the crop maturity stage.

The overall mean whitefly population recorded during the summer season was 7.06 adult whiteflies / plant. Similarly, Singh and Kalra (1995), Patil (2006) and Salam et al. (2009) reported that mean population of whitefly was 3.35 whiteflies/plant on summer mungbean, 6.65 whiteflies/plant on summer urdbean and 6.58 whiteflies/3 leaves on summer mungbean, respectively.

During the first and second year of study two peaks were obtained when the crop age was 35, 56 (*i.e.* 18th and 21st SW) and 49 and 63 (*i.e.* 16th and 18th SW) days old, respectively. The present findings are in conformity with findings of Ahirwar (2008), as he also reported two peaks of whitefly on mungbean (*i.e.* 16th and 17th SW).

However, Singh and Kalra (1995), Dar et al. (2002), Kumar et al. (2004), Patil (2006), Shivanna et al. (2009), Sharma et al. (2013) and Deole (2015) reported one peak during 21st, 25th, 26th, 21st, 16th, 17th, 21st, and 14th, SW on mungbean, urdbean, mungbean, cotton, tomato and brinjal, respectively. The differences in the peak periods of whitefly might be

attributed to the occurrence of the vulnerable stage of the host crops at varying growth periods.

During the peak period Max T, Min T, Morn and Even RH, WS, SS, Morn and Even VP, Evap and RF were 32.55^{0}C, 13.05^{0}C, 76.5%, 25.5%, 2.6 km/hr, 9.95 hrs, 10.45 mm, 9.0 mm, 4.3 mm and 0.0 mm, respectively. The present findings indicated that high temperature and low RH prevailed during the peak period were found to be favorable for the build-up of the pest population on the host crops (Singh and Kalra, 1995 and Ahirwar, 2008).

In the present findings Max T exhibited positive correlation with whitefly population, but statistically found to be non-significant. The present findings are in conformity with the findings of Singh and Kalra (1995), Patil (2006), Shivanna et al. (2009) and Sharma et al. (2013), as they also reported that Max T had positive influence on whitefly population on summer mungbean (NS-non-significant), cotton and tomato, respectively.

Further, Min T showed positive influence on whitefly population, but statistically found to be non-significant. The present findings are in agreement with the findings of Kumar et al (2004), Patil (2006) and Shivanna et al. (2009), as they also reported that Min T had positive effect on whitefly population on mungbean, cotton (NS) and urdbean, respectively.

In the present study SS exhibited positive association with whitefly population on soybean, but statistically found to be non significant. The present findings are partially in agreement with the findings of Kumar et al. (2004), as they also reported that SS exhibited significant positive correlation with the insect pest population on summer mungbean and urdbean. On the contrary, Patil (2006) reported that SS showed negative influence on the insect pest population on summer mungbean, but was statistically non significant.

In the present investigation Morn and Even RH showed significant negative correlation with whitefly population. The present findings corroborate the findings of Singh and Kalra (1995) and Sharma et al. (2013), as they also reported that Morn and Even RH exhibited significant negative influence on whitefly population on summer mungbean and urdbean and tomato,

respectively. On the contrary, Shivanna et al. (2009) reported that RH showed positive effect on whitefly population on cotton, but was statistically non significant.

In the present study RF showed significant negative influence on whitefly population, and are in partial agreement with the findings of Sharma et al. (2013), as they also reported that RF had negative effect on whitefly population on tomato, but was statistically non significant.

In the present investigation, Morn and Even VP exhibited significant negative influence on whitefly population.

Computation of multiple regression analysis with significant weather parameters and crop age were found to be responsible for almost 78% (R^2 value) variation in the whitefly population. The present findings confirms the findings of Sharma et al. (2013), as they also reported that the weather parameters strongly influenced the whitefly population to the extent of 89%.

Path analysis revealed that WS and Morn RH exhibited highest positive and negative direct effect on whitefly population, respectively and residual effect calculated was 0.1201, which indicated that the weather parameters and crop age included in the study were adequate to create an enormous impact on the whitefly population.

5.1.1.3. *Kharif* season

During first and second year of study, the first appearance of whitefly on soybean was observed on 7 DOC *i.e.* 29th SW (*i.e.*16th to 22nd July, 2015) and 27th SW (*i.e.* 2nd to 8th July, 2016), respectively. Present findings corroborates the findings of Bhatt (2008), Yadav (2013), Raghuvanshi et al. (2014), Ahirwar et al. (2015), Gour et al. (2015), Yadav et al. (2015) and Silodia (2016), as they also reported that the first appearance of whitefly on soybean ranged from 14-30 DOC (29th– 33rd SW). However, some workers have reported that it appeared in the late vegetative stage and it ranged from 34th SW (Kumar and Singh, 2016 and Singh et al. 2016) to 37th SW (Chandra and Rajak, 2004 and Yadav et al. 2016) on urdbean and cluster bean, respectively. The differences in the first appearance of the pest may be due to the variation in the date of sowing and crop phenology at different locations.

In the present study whitefly population was available upto the crop maturity stage (4th week of September *i.e.* 39th SW) and confirms the findings of Akbar et al. (2000), Raghuvanshi et al. (2014), Ahirwar et al. (2015), Gour et al. (2015) and Yadav et al. (2015), as they also reported the availability of the whitefly upto the maturity stage of the crop.

The overall mean population of whitefly recorded during the *kharif* season was 6.24 adult whiteflies/ plant. The present findings are in agreement with the findings of Rathore et al. (1998), Akbar et al. (2000), Bhatnagar and Dahiya (2005), Kooner and Harpreet (2007), Singh and Kumar (2011), Panduranga et al. (2011), Netam et al. (2013) and Nitharwal (2013), as they also reported that the mean population of whitefly ranged between 2.45-43.75 whiteflies/plant or 0.21 to 3.6 whitefly/leaf on crops like soybean, mungbean and urdbean.

In the present study whitefly population attained three peaks *i.e.* on 14 (30th SW), 28 (32nd SW) and 63 DOC (37th SW) during the first year, whereas two peaks *i.e.* on 28 (30th SW) and 63 DOC (35th SW) during the second year, respectively. Present findings are in accordance with the findings of Abd EL Samed et al. (2011), Ahirwar et al. (2015), Gour et al. (2015) and Yadav et al. (2015), as they also reported that whitefly attained two peaks on soybean during 27th and 33rd, 33rd and 35th and 33rd and 36th SW, respectively.

However, several corkers reported that the whitefly attained one peak during 32nd, 35th, 38th on (soybean), 36th on (mungbean), 37th on (urdbean) and 40th SW on (urdbean) (Chandra and Rajak 2004, Netam et al. 2013, Nitharwal 2013, Raghuvanshi et al. 2014, Kumar and Singh, 2016 and Silodia, 2016, respectively).

During the peak period Max T, Min T, Morn and Even RH, WS, SS, Morn and Even VP, Evap and RF ranged between 31.1-32.2^{0}C, 23.7-24.5^{0}C, 90.0-93.0%,70.0-79.0%, 4.6-6.4 km/hr, 3.0-6.1 hrs, 22.3-23.5 mm, 23.3-23.8 mm, 3.0-3.8mm and 35.2-83.6 mm, respectively. Present findings are in conformity with the findings of Sharma et al. (1997), Singh and Kumar (2011), Netam et al. (2013), Raghuvanshi et al. (2014) and Yadav et al. (2015), as they also reported that during the peak periods Max T, Min T, Morn and Even

RH and RF ranged from 31.5-33.7^{0}C, 21.8-25.3^{0}C, 90-93.4%, 51.9-81.0%, and 0-51 mm, respectively on soybean.

In the present study Max T showed positive impact on whitefly population, but statistically found to be non significant. Present findings are in conformity with the findings Abd EL Samed et al. (2011), Netam et al. (2013) and Yadav (2013), as they also reported that Max T had positive association with whitefly population on soybean. Similarly, positive influence of Max T on whitefly have been reported on mungbean (Kumar et al. 2007), urdbean (Rathore et al. 1998, Srivastava and Prajapati, 2012, Kumar and Singh, 2016 and Singh et al. 2017), cluster bean (Yadav et al. 2016), cotton (Selvaraj and Ramesh, 2012 and Kalkal et al. 2015) and horticultural crops *viz.* tomato, okra and brinjal (Borad, 1991, Kumawat et al. 2000 and Mane and Kulkarni, 2011). However, it contradicts the findings of Prasad et al. (2008), Sitaramaraju et al. (2010), Nitharwal (2013), Yadav (2013), Sharma and Kumar (2014), Gour et al. (2015) and Kumar and Singh (2016), as they reported that Max T had negative impact on whitefly population infesting soybean, urdbean and cotton, respectively.

In the present study, Min T showed positive correlation with whitefly population, but statistically found to be non significant. Similar findings have been reported by several workers (Rathore et al. 1998, Singh, 2011, Selvaraj and Ramesh 2012, Netam et al. 2013, Gour et al. 2015, Yadav et al. 2016, Kataria et al. 2017 and Singh et al. 2017) on urdbean, soybean, cluster bean and cotton.

On the contrary, negative relationship has been reported between Min T and whitefly population by Sitaramaraju et al. (2010), Yadav (2013) and Kumar and Singh (2016) on cotton, soybean and urdbean, respectively.

In the present study SS showed positive influence on whitefly population but statistically found to be non significant. The present findings are in agreement with the findings of Borad (1991), Kumar et al. (2004), Sharma and Rishi (2004a), Mane and Kulkarni (2011), Kumar and Sharma, Kalkal et al. (2015) and Kumar and Singh (2016), as they also reported that SS exhibited positive correlation with whitefly population infesting tomato, okra, mungbean, cotton, brinjal and mungbean, respectively.

However, it contradicts the findings of Gour et al. (2015), as they reported that SS exhibited negative relationship (non significant) with whitefly population on soybean.

In the present investigation Morn and Even RH had exhibited negative correlation with whitefly population, but was non significant. The present findings corroborates the findings of Rathore et al. (1998), as they also reported that Morn and Even RH had negative association with whitefly population on urdbean.

In the present findings RF exhibited negative correlation with whitefly population. The present findings confirms the findings of Sharma et al. (1997), as they also reported that RF exhibited negative correlation with whitefly population on soybean. Similar results have also been reported by several workers in cotton (Sharma and Rishi, 2004, Muhammad et al. 2006, Prasad et al. 2008, Kumar and Singh, 2014 and Kalkal et al. 2015), mungbean (Kumar et al. 2007 and Puneet et al. 2008), urdbean (Singh and Kumar, 2011 and Srivastava and Prajapati, 2012), brinjal (Mane and Kulkarni, 2011) and cluster bean (Yadav et al. 2016).

However, it contradicts the findings of several scientists (Mane and Kulkarni, 2011, Netam et al. 2013, Yadav, 2013, Gour et al. 2015, Yadav et al. 2016 and Singh et al. 2017), as they reported that RF had positive relationship with whitefly population on soybean, brinjal, cluster bean and urdbean.

Path analysis revealed that Min T and Morn VP exhibited highest positive and negative direct effect on whitefly population, respectively and the residual effect computed was 0.0316, which indicated that the weather parameters and crop age included in the study were adequate as they exercised a considerable influence on the whitefly population.

5.1.2. Incidence of yellow mosaic disease

5.1.2.1. Post *Kharif / Rabi* season

Pooled analysis of the data showed that the first incidence of YMD was observed when the crop age was 49±7 days and the Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population

were 23.7±2.7^{0}C, 10.2±1.8^{0}C, 86.5±2.5%, 54.5±2.5%, 3.2±0.05 km/hr, 6±2.3 hrs, 9.6±1.5 mm, 10.7±1.8 mm, 1.8±0.9 mm, 5.1±5.1 mm and 1.8±0.9 adult whiteflies/plant, respectively.

There was a gradual increase in the disease infection and it attained maximum (24.7±9.1%) on 112±7 DOC.

The present findings are in conformity with the findings of Panduranga et al. (2011), Salam et al. (2011), as they reported that the maximum YMD incidence was 40.0 and 12.6±10.0% on *rabi* mungbean, while Gopalaswamy et al. (2012) recorded 48.3±10% on *rabi* urdbean. Similarly, Biswas (2013) and Khan et al. (2013) also reported that the maximum YMD incidence was 97.5±2.5 and 30.9% on *rabi* soybean, respectively.

During the period of maximum YMD incidence, Max T, Min T, Morn RH, Even RH, WS, SS, Morn VP, Even VP, Evap and vector population were 37±1.9^{0}C, 18.5±1.1^{0}C, 67±1%, 17.5±5.5%, 3.5±0.2 km/hr, 9.3±0.8 hrs, 12.7±0.5 mm, 7.9±1.4 mm, 6.3±1.4 mm and 2.5±0.05 adult whiteflies/plant, respectively. Present findings are in conformity with the findings of Singh et al. (2009), as they also reported that during the period of maximum disease incidence, the Max T, Min T and RH were 31.1±4.2^{0}C and 13.3±2.9^{0}C, 73±1%, respectively. Present findings indicated that high temperature coupled with low rainfall and presence of vector population were found to be favourable for the outbreak of the disease (Biswas, 2013).

In the present study independent factors *viz.* Max T, Min T, Even VP, Evap, whitefly population and crop age of the same week, preceding one and two weeks of YMD incidence, exhibited significant positive correlation with YMD incidence.

Further, Even VP of same and preceding two weeks of YMD incidence showed significant positive impact on the disease infection.

Computation of multiple regression analysis with significant independent factors of same week, preceding one and two weeks of YMD incidence were found to be responsible for almost 96, 95 and 99% (R^2) variation in the disease incidence, respectively.

5.1.2.2. Summer season

The first incidence of YMD (1.6±0.5%) in summer soybean was observed on soybean when the crop age was 24.5±3.5 days *i.e.* during the last week of April. Similarly, Murugesan and Chelliah (1977) and Sree et al. (2018) reported that the first disease incidence was observed during the month of March in mungbean (YMD) and okra (YVMV), respectively.

Difference in the first appearance of the viral disease may be attributed to the variation in the sowing date and susceptibility status of the variety against the vector/ disease and the crop phenology coupled with environment conditions which prevailed during that period.

The present findings are partially in conformity with the findings of Singh and Kalra (1995) and Singh et al. (2011), as they also reported that during first incidence of the disease, the intensity was 7.5 and 10.0% YMD in urdbean and mungbean and 3.6-5.3%TLCV in tomato.

During the first incidence of the YMD on soybean the Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 36.6±0.8^{0}C, 18.4±2.0^{0}C, 71±7%, 17.5±0.5%, 3.1±0.8 km/hr, 9.6±0.4 hrs, 14.2±1.3 mm, 8±0.9 mm, 5.6±0.9 mm, 5±3.5 mm and 6.0±0.15 adult whiteflies/plant, respectively.

There was a gradual increase in the disease infection and it attained maximum (64.4±3.3%) on 80.5±10.5 DOC.

The present findings are in partial accordance with the findings of several workers *viz.,* Singh and Kalra, 1995 and Singh et al. 2011, Khan et al. 2013 and Sree et al. 2018, as they also reported that the maximum incidence of viral disease was about 17.5% YMD in mungbean and 21.2% YMD in urdbean, 80% TLCV in cotton, 30.9% YMD in soybean and 28.1% YVMV in okra, respectively.

During the period of maximum incidence of YMD, Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, and Evap were 40.7±0.9^{0}C, 26.6±2.0^{0}C, 54±8%, 23.5±3.5%, 6.2±0.05 km/hr, 8.6±0.3 hrs, 17.7±1.15 mm, 13.4±1.05 mm, 7.7±1.2 mm, 8.1±7.6 mm and 3.7±3.3 adult whiteflies/plant, respectively.

The increased disease incidence might be attributed to the higher temperature which prevailed during the cropping season, seemed found to be congenial for the development and multiplication of the vector, *B. tabaci* which in turn favoured the transmission of the disease (Murugesan and Chelliah, 1977 and Nath, 1994).

In the present investigation independent factors *viz.* Max T, Min T, WS, Evap and crop age of the same week, preceding one and two weeks of YMD incidence exhibited significant positive influence on the disease incidence.

Present findings are in conformity with the findings of Nath (1994), Singh et al. (2011) and Sree et al. (2018), as they also reported that Max T had significant positive impact on YMD incidence in mungbean, tomato and okra, respectively.

The present findings also confirms the findings of Sree et al. (2018), as they also reported that Min T showed significant relationship with YMD incidence in okra.

Morn and Even VP of the same week exhibited significant positive association with YMD incidence.

In the present investigation vector population (*B.tabaci*) exhibited negative correlation with YMD incidence but, statistically found to be non significant. However, it contradicts the findings of Sahoo and Sahu (1991), as they reported that the vector population had positive influence on the disease incidence in urdbean.

Computation of multiple regression between the significant independent factors of same week, preceding one and two weeks of YMD infection, showed that the abiotic factors, vector population and crop age influenced the disease incidence to the extent of 99%, 98% and 99%, respectively.

5.1.2.3. *Kharif* season

The first incidence of YMD recorded when the soybean crop age was 24.5±3.5 days and the disease intensity was 5.5±4.4%.

Present findings are partially in agreement with the findings of Bhatnagar and Dahiya (2005), Salam et al. (2011), Silodia (2016) Srinivasaraghavan et al. (2016), as they also reported that during the first incidence of YMD, the disease intensity ranged from 0.4 to 3.0% on urdbean, mungbean and soybean.

During the first incidence of YMD, the Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 30.7±0.9^{0}C, 23.8±0.2^{0}C, 90.5±0.5%, 68.5±1.5%, 6.4±1.9 km/hr, 4.7 hrs, 22.2±0.9 mm, 21.3±1.1 mm, 3.5±0.1 mm, 105.8±44.0 mm and 6.4±4.0 adult whiteflies/plant, respectively.

Thereafter, the disease infection increased gradually and attained maximum (81.11±18.89%) on 73.5±17.5 DOC.

Similar findings have been reported by several workers (Bhatnagar and Dahiya, 2005, Kooner and Harpreet, 2007, Singh et al. 2009, Salam et al. 2011, Khan et al. 2013, Silodia, 2016 and Srinivasaraghavan et al. 2016), that the maximum YMD disease intensity ranged from 0.2-47.1% in mungbean, 33-100% in urdbean, 30.9-60% in soybean and more than 80% in Indian bean.

In the present investigation the maximum disease incidence was observed when the crop age was 73.5±17.5 days and it contradicts the findings of Gupta and Keshwal (2003) as they reported that maximum incidence on soybean was recorded on 45 DOC. The difference in the vulnerable age of the crop may be attributed to the date of sowing, YMD susceptible/resistant variety included in the study coupled with the availability of the viruliferous vectors.

During the period of maximum YMD incidence, the Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 31.0±1.15^{0}C, 23.8±0.3^{0}C, 90.5±3.5%, 70±13%, 3.7±0.2 km/hr, 5.6±1.0 hrs, 21.9±0.4 mm, 21.7±0.9 mm, 3.2±0.2 mm, 30.5±21.8 mm and 5.7±5.5 adult whiteflies/plant, respectively. The present findings confirms the findings of Gupta and Keshwal (2002), Gupta and Keshwal (2003), Biswas

(2003) and Singh et al. (2009), as they also reported that during the maximum incidence of YMV the Max T, Min T, RH, SS and RF were 31.1±4.2^{0}C, 17.3±6.9^{0}C and 78.5±6.5%, 4.6 hrs and 14.0 mm, respectively.

In the present study crop age and Min T of the same week, preceding one and two weeks of YMD incidence exhibited significant positive and negative impact on the disease incidence, respectively.

Present findings are in agreement with the findings of Sharma and Rishi (2004), as they also reported that Min T exhibited significant negative impact on CLCV in cotton. However, it contradicts the findings of Safdar et al. (2005) and Khan et al. (2012), as they reported that Min T had exhibited significant positive influence on YVMV in okra and MYMV in mungbean, respectively.

Further, the vector population preceding two weeks of YMD incidence had significant positive impact on YMD incidence.

Abiotic factors *viz.,* SS and WS of the same week showed significant positive and negative correlation with YMD incidence, respectively. The present findings confirms the findings of Sharma and Rishi (2004), as they also reported that SS and WS exhibited significant positive and negative influence on CLCV in cotton, respectively. On the contrary, Safdar et al. (2005) reported that WS had significant positive influence on YVMV in okra.

In the present investigation RF of the same week exhibited significant negative impact on YMD incidence. Present findings are in accordance with the findings of Khan et al. (2012) and Srivastava and Prajapati (2012), as they also reported that RF had negative influence on YMD in mungbean and urdbean, respectively.

Computation of multiple regression equations between significant independent factors of same week, prior to one and two weeks of YMD incidence were found to be responsible for influencing the disease incidence to the tune of 98%, 99% and 96% (R^2), respectively.

5.2. To study the presence of MYMIV in whitefly and soybean plant through molecular technique.

In order to understand the relationship between viruliferous whiteflies and disease expansion in the soybean host plant, the natural adult whiteflies and soybean leaf samples were collected from the soybean experimental field during three consecutive seasons *viz. rabi*, summer and *kharif*. A total of 20 adult whitefly and leaf samples were collected from 7 days old crop (DOC) and repeated at weekly intervals for the detection of MYMIV which was carried out by using specific primers *i.e.* Coat protein CP-(DNA-A) and DNA-B through PCR technique.

5.2.1. Post *Kharif/ Rabi* season

During the *rabi* season, PCR results revealed that all the whitefly samples collected from 7 and 14 days old crop (DOC) were found to be non viruliferous *i.e.* absence of MYMIV. The whitefly samples collected from 24.5±3.5 DOC onwards were found to be viruliferous. The DNA-A contains the information required for replication and encapsidation of viral DNA, while DNA-B codes for protein movement which is responsible for the systemic infection, spread of the virus and disease symptom development (Basu and Giri, 1992).

During the first detection of the virus in the vector samples, the Max T, Min T, Morn RH and Even RH were 23±0.8^{0}C, 8.1±3.3^{0}C, 89.5±2.5% and 48±16.5%, respectively. The molecular studies of the vector throughout the entire cropping season indicated that the DNA-A and B registered their presence in the samples, which ranged from 0 to 100 and 20 to 100%, respectively.

After the first detection of both the DNA-A and B, their presence gradually increased with slight fluctuations observed in the samples collected from 42, 56 and 91 DOC. However, both the DNA's were available upto the maturity stage of the crop where all the vector samples were found to be viruliferous.

On the other hand, the MYMIV was first detected in the leaf samples on 42±7 DOC. During this period the Max T, Min T, Morn RH and Even RH

were 24.9±2.7^{0}C, 7.2±1.9^{0}C, 91.5±0.5% and 36±1%, respectively. The virus from the vectors were transmitted in 14±7 days in the host plants, while the first disease symptoms were observed after 7 days of MYMIV detection *i.e.* when the crop age was 48±7days. The maximum virus infection was recorded on 52.5±3.5 days old crop when the Max T, Min T, Morn RH and Even RH were 24.7±3.7^{0}C, 11.7±0.4^{0}C, 88.5±0.5% and 57.5±17.5%, respectively. The results indicated that the temperature and RH played a lead role in influencing the virus infection. Present findings confirms the findings of Singh et al. (2009), as they also reported that during the period of maximum disease incidence on Indian bean, the Max T, Min T and RH were 31.1±4.2^{0}C and 13.3±2.9^{0}C and 73±1%, respectively.

5.2.2 Summer season

During the summer season PCR results indicated that all the whitefly samples collected from 7 DOC were found to be non viruliferous. However, the first detection of MYMIV DNA-A and B were observed in the samples collected on 14 DOC and the abiotic factors *viz.* Max T, Min T, Morn RH and Even RH were 35.2±1.3^{0}C, 16.9±1.9^{0}C, 80±5% and 36±1%, respectively. The molecular studies of the vector throughout the entire cropping season indicated that the DNA-A and B registered their presence in 25-90 and 15-95%, respectively.

After the first detection of both the DNA-A and B, their presence gradually increased with slight fluctuations observed in the samples collected from 21, 42, 70 DOC. However, both the DNA's were available upto the maturity stage of the crop where all the vector samples were found to be viruliferous.

The MYMIV was first detected in the leaf samples on 14 DOC, and the abiotic factors *viz.* the Max T, Min T, Morn RH and Even RH were 32.2±1.3^{0}C, 16.9±1.9^{0}C, 80±5% and 36±1%, respectively.

The virus from the vectors were transmitted in 7 days in the host plants, while the first disease symptoms were observed after 10.5±3.5 days of MYMIV detection *i.e.* when the crop age was 24.5±3.5days. The maximum virus infection was recorded on 31.5±3.5 days old crop, when the Max T, Min

T, Morn RH and Even RH were 39.1±0.05^{0}C, 22±1.9^{0}C, 52±10% and 17.5±0.5%, respectively. The results indicated that the temperature and RH during the cropping season favoured the vector multiplication and YMD disease infection.

Similar findings have been reported by Nath (1994), Gupta and Keshwal (2003), Singh et al. (2011) and Sree et al. (2018), as they also reported that Max T had significant positive impact on YMD incidence in soybean, mungbean, tomato and okra, respectively.

5.2.3 *Kharif* season

During the *kharif* season, it is evident from the PCR assay that the whitefly samples collected from 7 DOC and onward, were found to be viruliferous *i.e.* presence of MYMIV.

During the first detection of the virus in the vector population, the Max T, Min T, Morn RH and Even RH were 30.5±1^{0}C, 23.6±0.5^{0}C, 91.5±2.5% and 75.5±5.5%, respectively. The molecular studies of the vector throughout the entire cropping season revealed that the DNA- A and B were present in 20-90 and 25-100%, respectively.

After the first detection of both the DNA-A and B, their presence gradually increased with slight variation observed in the samples collected from 21, 35, 56 DOC. However, both the DNA's were available upto the maturity stage of the crop where all the vector samples were found to be viruliferous.

On the other hand, the MYMIV was first detected in the leaf samples on 17.5±3.5 DOC. During this period the Max T, Min T, Morn RH and Even RH were 30.5±1^{0}C, 23.7±0.2^{0}C, 89±2% and 68±1%, respectively.

The virus from the vectors were transmitted in 10.5±3.5 days in the host plants, while the first disease symptoms were observed after 7 days of MYMIV detection *i.e.* when the crop age was 24.5±3.5days. The maximum virus infection was recorded on 28±7 days old crop, when the Max T, Min T, Morn RH and Even RH were 30.4±0.6^{0}C, 23.4±1^{0}C, 90% and 73.5±3.5%, respectively.

Present findings corroborates with the findings of Gupta and Keshwal (2002), Gupta and Keshwal (2003), Biswas (2003) and Singh et al. (2009), as they also reported that during the maximum incidence of YMV, the Max T, Min T and RH were 31.1±4.2^{0}C, 17.3±6.9^{0}C and 78.5±6.5%, respectively.

Several workers have reported various crops *viz.* mungbean, yard long bean, mothbean, cowpea, kidney been, French bean, pigeonpea, urdbean and soybean (Hussain et al. 2004, Malathi et al. 2005, Qazi et al. 2006, Naimuddin and Akram, 2010, Kamaal et al. 2011, Islam et al. 2012, Sahid et al. 2012, Singh et al. 2013, Jeevan et al. 2014, Ramesh et al. 2016, Silodia, 2016, Nair et al. 2017 and Marabi et al. 2017) and weeds *viz.* wild spp. of *Vigna*, *Ageratum conyzoids*, *Corchorus olitorius*, *Alternanthra sessilis, Vigna trilobita*, *Sida acuta*, *Sida rhombifolia, Malvastrum coromandelianum, Eclipta alba*, *Bracaria ramose* and *Aclalypha indica* (Naimuddin et al. 2011, Naimuddin et al. 2014, Marabi et al. 2017 and Ramesh et al. 2017) to harbor vector whitefly and also serve as hosts of MYMIV. These crops and most of these weeds are prevalent in this location which might be serving as a reservoir of MYMIV leading to the development of a strong potential inoculum and under congenial weather conditions it results in the disease outbreak in the host crops which are cultivated in the forthcoming season.

5.3. To study the virus (MYMIV)-vector (*B. tabaci*) relationship in soybean in insect proof net house.

5.3.1. Acquisition access period (AAP)

In the present study acquisition period significantly influenced the transmission of virus and disease expression period. Minimum acquisition feeding period required by the non viruliferous whiteflies, *B. tabaci* to acquire virus from MYMIV infected plant was 0.5 h, which transmitted 15% YMD infection in the soybean plants and the disease symptoms first appeared in 26.1 days. Present findings are in conformity with the findings of Czosnek et al. (2002), Mann and Singh (2004a) and Haq et al. (2018), as they also reported that the minimum AAP required by whitefly was 0.25, 0.33 and 0.5 h to transmit the TYLCV (tomato yellow leaf curl virus) and CLCuv (cotton leaf curl virus) in tomato and cotton, respectively.

However, it contradicts the findings of Mansour and Al-Musa (1992), Khan and Ahmad (2005) and Njoroge et al. (2017), as they reported that the whitefly required a minimum AAP of 1 h, 4 h and 6 h to transmit TYLCV, CLCuV and cassava mosaic virus in tomato, cotton and cassava, respectively. Variation observed in the severity of disease symptoms and infectivity might be due to the susceptibility status of the host plant genotypes (Malathi et al. 2005).

The present findings indicated that with the increase in the acquisition feeding period, there was a gradual increase in the infection rate coupled with decrease in the disease symptom expression period. The present findings confirms the findings of Nagata et al. (2007), as they also reported that with the increase in the acquisition feeding period there was an increase and decrease in the disease incidence and disease symptom expression period, respectively in tomato.

In the present study with 12 h of acquisition feeding period, 100% disease infection was observed and the disease symptoms appeared in 20.6 days which further reduced to 18.9 days at 24 h AAP, but were at par with each other. Present findings are in accordance with the findings of Rajnimala et al. (2005), as they also reported that 12 h of AAP resulted in 100% Bitter gourd YMV disease infection in bitter gourd (BG).

Present findings are partially in accordance with the findings of Nariani (1960), Biswas (2002) and Gazala et al. (2013), as they reported that at higher AAP of 24 h and 18 h, the YMD disease symptoms appeared in the soybean seedling in 18-20 days after inoculation, and the infection intensity varied from 50-88.8%.

However, the present findings contradicts the findings of Ghanim et al. (2001), as they reported that the whitefly was able to transmit 100% TYLCV when given an AAP of 48 h.

In the present study AAP exhibited significant positive and negative relationship with MYMIV infection and disease symptom expression period, respectively (Mann and Singh 2004b).

5.3.2. Inoculation access period (IAP)

In the present experiment, inoculation access period had significant impact both on the transmission of MYMIV infection and the disease symptom expression period. The viruliferous adult female whiteflies required a minimum inoculation period of 1 h to transmit 10% YMD infection in the soybean plants and the first disease symptoms appeared in 24 days. Present findings are in conformity with the findings of Khan and Ahmad (2005) and Senanayake et al. (2012), as also they reported that a minimum 1 h of IAP was required by whitefly for successful transmission of CLCuV and Chilli LCuV in cotton and chilli, respectively.

The present findings contradicts the findings of Mann and Singh (2004a), Haq et al. (2018), Czosnek et al. (2002) and Njoroge et al. (2017), as they reported that the whitefly required low (10, 20 and 30 min) or high IAP (6 h) for successful transmission of virus *viz.,* CLCuV, TYLCV and CMV (cassava mosaic virus) in cotton, tomato and cassava, respectively.

In the present studies 18 h of inoculation period resulted in 100% disease infection and the disease symptoms appeared in 17.5 days, which reduced to 15.8 days at 24 h IAP, but no significant differences were observed between them.

Present findings are not in agreement with the findings of Lapidot (2007) and Kamaal et al. (2011), as they reported that the viruliferous whiteflies required 48 h for transmitting 100% MYMIV and TYLCV infection in urdbean and tomato, respectively.

In the present study IAP exhibited significant positive and negative association with MYMIV infection and disease symptom expression period, respectively (Mann and Singh, 2004b).

5.3.3. Effect of vector population

In the present investigation population density of viruliferous adult female whitefly significantly influenced the transmission of MYMIV infection and disease symptom expression period. A single viruliferous adult female whitefly/plant was able to transmit YMD infection (15%) in soybean plants when it was given 24 h each of AAP and IAP, and the disease symptoms

appeared in 27.3 days. Present findings corroborates the findings of Aidawati et al. (2002), Mann and Singh (2004), Yadav et al. (2009) and Senanayake et al. (2012), as they also reported that a single whitefly was able to transmit the ToLCV (tobacco leaf curl virus) in tobacco, CLCuV in cotton, MYMIV in soybean and Chilli LCuV (chilli leaf curl virus) in chilli, respectively.

On the contrary Rajnimala et al. (2005) reported that a minimum of 5 whiteflies were required to transmit the Bitter gourd YMV in bitter gourd. Variations observed might be attributed to the host plant factors which influence the plant susceptibility to viral infection and it includes inherent genetic traits and also the plant age at the time of inoculation (Basu and Giri, 1992).

In the present study a population density of 10 viruliferous adult whiteflies/ plant transmitted 100% disease infection and the symptoms appeared in 18.4 days. Moreover, the disease symptom expression period reduced to 13.9 and 13 days when the vector population was increased to 15 and 20 viruliferous whiteflies/ plant, but they did not differ significantly from each other.

In the present investigation, population density of viruliferous adult female whitefly was found to be directly proportional to the disease transmission. Similar findings have been reported by several workers (Mehta et al. 1994, Aidawati et al. 2002, Mann and Singh, 2004, Rajnimala et al. 2005, Lapidot, 2007, Yadav et al. 2009, Shivakumar, 2010, Senanayake et al. 2012, Srinivasan et al. 2012, Bag et al. 2014, Govindan et al. 2014 and Njoroge et al. 2017) during the transmission study of TLCV, ZLCV (Zinnia leaf curl virus), MYMV, CLCV, BGYMV, Chilli LCuV and CMV in tomato, Zinnia, legumes (mungbean, urdbean and soybean), cotton, bitter gourd, chilli and cassava, respectively.

In the present study viruliferous whitefly/plant exhibited significant positive and negative correlation with MYMIV infection and symptom expression period, respectively. The present findings confirms the findings of Mann Singh (2004), as they also reported that the population density of vector

(*B. tabaci*) was inversely proportional to the CLCuV disease symptom expression period in cotton.

5.3.4. Retention period

In the present study the results revealed that the vector started transmitting the virus from 1st day of the serial transfer and the retention period was observed upto 15th day. The maximum disease infection was observed on the 2nd day, thereafter, the disease infection gradually declined with slight fluctuations on the 5th and 11th day of the serial transfer. Whereas, the mortality of the vectors started from 11th day and it was maximum on the 16th day of the serial transfer.

The present findings corroborates the findings of Mansour and Al-Musa (1992), Snananayake et al. (2012) and Haq et al. (2018), as they also reported that the retention period of the TLCV and Chilli LCuV in the vector was 10-11 and 5 days, respectively.

In the present investigation serial transfer days exhibited significant negative impact on MYMIV infection.

SUMMARY, CONCLUSION AND SUGGESTIONS FOR FURTHER WORK

6.1 SUMMARY

Present research work on "**Studies on whitefly, *Bemisia tabaci* Genn., vector of mungbean yellow mosaic India virus with special reference to seasonal fluctuation and virus-vector relationship in soybean**" was carried out in the Experimental Farm, Adhartal Tank area, College of Agriculture, JNKVV, Jabalpur (M.P.) during three consecutive seasons (*rabi*, summer and *kharif*) of 2014-15, 2015-16 and 2016-17. Studies on virus-vector relationship were carried out in insect proof net house during *kharif* 2015-16 and 2016-17. The experiment was conducted with the following objectives:

1. To study the seasonal incidence of whitefly and yellow mosaic disease in soybean crop.
2. To study the presence of MYMIV in whitefly and soybean plant through molecular technique.
3. To study the virus (MYMIV)-vector (*B. tabaci*) relationship in soybean in insect proof net house.

6.1 To study the seasonal incidence of whitefly and yellow mosaic disease in soybean crop

6.1.1 Whitefly, *Bemisia tabaci* Genn. (Hemiptera: Aleyrodidae)

6.1.1.1 Post *Kharif* / *Rabi* season

The first incidence of whitefly on soybean was observed on 7 days old crop (DOC) *i.e.* 49th SW and 1st SW during first and second year, respectively and was available upto the crop maturity stage. The overall mean population of whitefly recorded during the *rabi* season was 2.30 adult whiteflies/plant.

During the first and second year of study, two and three peaks were obtained when the crop age was 84, 112 (8th and 12th SW) and 35, 63 and 91 (5th, 9th and 13th) DOC, respectively. During peak periods of whitefly population Max T, Min T, Morn RH, Even RH, WS, SS, Morn VP, Even VP,

Evap and RF were ranged between 22.2-32.5^{0}C, 8.4-13.0^{0}C, 76.5-91.5%, 25.5-51.0%, 2.6-3.5 km/hr, 6.8-9.9 hrs, 8.5-10.5 mm, 9.0-9.5 mm, 1.5-4.3 mm and 0.0-6.1 mm, respectively.

Correlation studies revealed that the Max T, Min T, Evap and crop age exhibited significant positive influence on whitefly population. However, multiple regression analysis with significant weather parameters and crop age showed that independent variables were responsible for about 74% (R^2 value) variation in the whitefly population.

Path analysis revealed that the Morn VP and Morn RH exhibited highest positive and negative direct effect on whitefly population, respectively and the residual effect computed was 0.2055, which indicated that the weather parameters and crop age included in the study were adequate as they exerted a major impact on the whitefly population.

6.1.1.2. Summer season

During first and second year of study during the summer season, the first appearance of whitefly on soybean was observed on 7 DOC *i.e.* 14th SW and 10th SW, respectively and were available up to the crop maturity stage. The overall mean whitefly population recorded during the summer season was 7.06 adult whiteflies / plant.

During the first and second year of study, two peaks were recorded when the crop age was 35, 56 (*i.e.* 18th and 21st SW) and 49 and 63 (*i.e.* 16th and 18th SW) days old, respectively. During the peak period, Max T, Min T, Morn and Even RH, WS, SS, Morn and Even VP, Evap and RF were 32.5^{0}C, 13.0^{0}C, 76.5%, 25.5%, 2.6 km/hr, 9.9 hrs, 10.4 mm, 9.0 mm, 4.3 mm and 0.0 mm, respectively.

Correlation studies revealed that the Max T, Min T and SS exhibited positive correlation with whitefly population, but were statistically was non-significant. Whereas, Morn and Even RH Morn and Even VP and RF showed significant negative impact on whitefly population.

Computation of multiple regression analysis with significant weather parameters and crop age were found to be responsible for almost 78% (R^2 value) variation in the whitefly population. Path analysis revealed that WS and

Morn RH were exhibited highest positive and negative direct effect on whitefly population, respectively and residual effect calculated was 0.1201.

6.1.1.3. *Kharif* season

During first and second year of study, the first appearance of whitefly on soybean was observed on 7 DOC *i.e.* 29th SW and 27th SW, respectively and the pest was available upto the crop maturity stage (4th week of September *i.e.* 39th SW). The overall mean population of whitefly recorded during the *kharif* season was 6.24 adult whiteflies/ plant.

The whitefly population attained three peaks *i.e.* on 14 (30th SW), 28 (32nd SW) and 63 DOC (37th SW) during the first year, whereas two peaks *i.e.* on 28 (30th SW) and 63 DOC (35th SW) during the second year, respectively. During the peak period, Max T, Min T, Morn and Even RH, WS, SS, Morn and Even VP, Evap and RF ranged between 31.1-32.2^{0}C, 23.7-24.5^{0}C, 90.0-93.0%,70.0-79.0%, 4.6-6.4 km/hr, 3.0-6.1 hrs, 22.3-23.5 mm, 23.3-23.8 mm, 3.0-3.8mm and 35.2-83.6 mm, respectively.

Correlation studies revealed that the Max T, Min T, SS and crop age had positive impact on whitefly population, but statistically found to be non significant.

Path analysis revealed that Min T and Morn VP exhibited the highest positive and negative direct effect on whitefly population, respectively. Residual effect computed was 0.0316, which indicated that the weather parameters and crop age included in the study were adequate as they exercise a considerable influence on whitefly population.

6.1.2. Yellow mosaic disease

6.1.2.1. Post *Kharif* / *Rabi* season

The first incidence of yellow mosaic disease was observed when the crop age was 49±7 days, when the Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 23.7±2.7^{0}C, 10.2±1.8^{0}C, 86.5±2.5%, 54.5±20.5%, 3.2±0.05 km/hr, 6±2.3 hrs, 9.6±1.5 mm, 10.7±1.8 mm, 1.8±0.9 mm, 5.1±5.1 mm and 1.8±0.9 adult

whiteflies/plant, respectively. The YMD incidence was gradually increased and it attained maximum YMD incidence (24.7±9.1%) on 112±7 DOC.

During the period of maximum incidence of YMD, the Max T, Min T, Morn RH, Even RH, WS, SS, Morn VP, Even VP, Evap and vector population were 37±1.9^{0}C, 18.5±1.1^{0}C, 67±11%, 17.5±5.5%, 3.5±0.2 km/hr, 9.3±0.8 hrs, 12.7±0.5 mm, 7.9±1.4 mm, 6.3±1.4 mm and 2.5±0.05 adult whiteflies/plant, respectively.

Correlation studies revealed that independent factors *viz.* Max T, Min T, Even VP, Evap, whitefly population and crop age of the same week, preceding one and two weeks of YMD incidence exhibited significant positive correlation with YMD incidence.

Further, Even VP of same and preceding two week of YMD incidence showed significant positive impact on YMD incidence.

Computation of multiple regression analysis with significant independent factors of same week, preceding one and two weeks of YMD incidence were found to be responsible for almost 96, 95 and 99% (R^2) variation in the disease incidence, respectively.

6.1.2.2. Summer season

The first incidence of yellow mosaic disease in summer soybean was observed on soybean when the crop age was 24.5±3.5 days. During the first incidence (2.2±1.1%) of the YMD Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 36.6±0.8^{0}C, 18.45±2.05^{0}C, 71±7%, 17.5±0.5%, 3.1±0.8 km/hr, 9.6±0.4 hrs, 14.2±1.3 mm, 8±0.9 mm, 5.65±0.95 mm, 5±3.5 mm and 6.05±0.15 adult whiteflies/plant, respectively.

The YMD incidence was gradually increased and attained maximum 64.45±3.33% on 80.5±10.5 DOC. During peak period of YMD incidence Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, and Evap were 40.7±0.9^{0}C, 26.65±2.05^{0}C, 54±8%, 23.5±3.5%, 6.25±0.05 km/hr, 8.6±0.3 hrs, 17.75±1.15 mm, 13.45±1.05 mm, 7.7±1.2 mm, 8.1±7.6 mm and 3.7±3.3 adult whiteflies/plant, respectively.

Correlation study revealed that independent factors *viz.* Max T, Min T, WS, Evap and crop age of the same week, preceding one and two weeks of YMD incidence exhibited significant positive influence on YMD incidence. Whereas, Max T, Min T, Morn and Even VP of same week exhibited significant positive association with YMD incidence.

Computation of multiple regression (R^2) between the significant independent factors of same week, preceding one and two week of YMD incidence were showed the abiotic factors, vector population and crop age influenced the disease incidence to the extent of 99%, 98% and 99%, respectively, which indicated that included independent factors were sufficient to influence the YMD infection in summer soybean.

6.1.2.3. *Kharif* season

The first incidence of YMD recorded was 5.5±4.4% on soybean when the crop age was 24.5±3.5 days. During the first incidence of YMD, Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 30.75±0.95^{0}C, 23.8±0.2^{0}C, 90.5±0.5%, 68.5±1.5%, 6.4±1.9 km/hr, 4.7 hrs, 22.25±0.95 mm, 21.35±1.15 mm, 3.55±0.15 mm, 105.85±44.05 mm and 6.45±4.05 adult whiteflies/plant, respectively.

Thereafter, the disease incidence was increased gradually and attained maximum 81.11±18.89% on 73.5±17.5 DOC. During the period of maximum YMD incidence Max T, Min T, Morn RH and Even RH, WS, SS, Morn VP, Even VP, Evap, RF and vector population were 31.05±1.15^{0}C, 23.85±0.35^{0}C, 90.5±3.5%, 70±13%, 3.75±0.25 km/hr, 5.65±1.05 hrs, 21.9±0.4 mm, 21.7±0.9 mm, 3.20±0.20 mm, 30.55±21.85 mm and 5.7±5.50 adult whiteflies/plant, respectively.

Correlation studies revealed that the crop age having YMD incidence of the same week, preceding one and two weeks of YMD incidence had exhibited significant positive impact on YMD incidence. Whereas, Min T of the same week, preceding one and two weeks of YMD incidence exhibited significant negative impact on YMD incidence. While, vector population of preceding two weeks showed significant positive impact on YMD incidence.

Further, SS of the same week exhibited significant positive association, whereas WS and RF of same week exhibited significant negative impact on YMD incidence.

Computation of multiple regression (R^2) obtained between significant independent factors of same week, prior to one and two weeks of YMD incidence were found to be responsible for influencing the disease incidence to the extent of 98%, 99% and 96%, respectively.

6. 2. To study the presence of MYMIV in whitefly and soybean plant through molecular technique

6.2.1. *Rabi* season

During the *rabi* season MYMIV could not be detected in the vector samples collected from 7 to 14 DOC, while it was first detected on 24.5±3.5 DOC. DNA-A and B detected in the samples throughout the cropping season ranged from 0 to 100% and 20 to 100%, respectively. However, during the *rabi* season the virus inoculum in vectors and plants was very low.

The first detection of virus in the leaf samples was found on 42±7 DOC. The transmission of virus from the vectors to host plant was observed in 14±7 days. The maximum virus infection was recorded on 52.5±3.5 days old crop when the Max T, Min T, Morn RH and Even RH were 24.7±3.7^{0}C, 11.7±0.4^{0}C, 88.5±0.5% and 57.5±17.5%, respectively.

6.2.2. Summer season

In the summer season the first detection of MYMIV DNA-A and B were observed in the vector samples collected on 14 DOC and during the cropping season it ranged from 25-90 and 15-95%, respectively.

MYMIV was first detected in the leaf samples on 14 DOC and during the period the abiotic factors *viz.* the Max T, Min T, Morn RH and Even RH were 32.2±1.3^{0}C, 16.9±1.9^{0}C, 80±5% and 36±1%, respectively.

The virus from the vectors were transmitted in 7 days in the host plants, while the first disease symptoms were observed after 10.5±3.5 days of MYMIV detection *i.e.* when the crop age was 24.5±3.5days. The maximum virus infection was recorded on 31.5±3.5 DOC. During this period the Max T, Min T, Morn RH and Even RH were 39.1±0.5^{0}C, 22±1.9^{0}C, 52±1% and 17.5±0.5%, respectively.

6.2.3. *Kharif* season

During the *kharif* season vector samples collected from 7 DOC were found to be viruliferous and it continued till the crop maturity stage.

During the first detection of the virus in the vector samples, the Max T, Min T, Morn RH and Even RH were 30.5±1^{0}C, 23.6±0.5^{0}C, 91.5±2.5% and 75.5±5.5%, respectively. DNA-A and B were present in the samples analyzed throughout the cropping season ranged 20-90 and 25-100%, respectively.

The MYMIV from the leaf samples were first detected on 17.5±3.5 DOC. The virus from the vectors were transmitted in the host plants in 10.5±3.5 days, while the disease symptoms first appeared after 7 days of MYMIV detection *i.e.* when the crop age was 24.5±3.5 days. The maximum leaf samples were found positive with MYMIV on 28±7 days old crop, when the Max T, Min T, Morn RH and Even RH were 30.4±0.6^{0}C, 23.4±1^{0}C, 90% and 73.5±3.5%, respectively.

The findings indicated that irrespective of crop season, the temperature and RH during the cropping season influenced the vector multiplication and disease infection.

6.3 To study the virus (MYMIV)-vector (*B. tabaci*) relationship in soybean in insect proof net house

6.3.1 Acquisition access period (AAP)

The differences in the transmission of MYMIV infection and disease symptom expression period among different acquisition feeding periods were significant. The adult female whitefly required a minimum acquisition access period of 0.5 h which transmitted 15% YMD infection in the soybean plants and the disease symptoms first appeared in 26.1 days.

However, 12 h of acquisition feeding period, the vector transmitted 100% disease infection in the host plants and the disease symptoms appeared in 20.6 days which further reduced to 18.9 days at 24 h AAP, but both were at par with each other.

Correlation studies revealed that AAP showed significant positive and negative relationship with MYMIV infection and disease symptom expression period, respectively.

6.3.2 Inoculation access period (IAP)

The viruliferous adult female whiteflies required a minimum inoculation period of 1 h which transmitted 10% YMD infection in the plants and the first disease symptoms appeared in 24 days.

Correlation studies revealed that IAP exhibited significant positive and negative correlation with MYMIV infection and disease symptom expression period, respectively.

However, 18 h of inoculation access period, 100% disease infection was recorded and the disease symptoms appeared in 17.5 days, which reduced to 15.8 days at 24 h IAP, but there was a non significant.

Inoculation period was found to be directly proportional to the infection rate and inversely proportional to the disease symptom expression period.

6.3.3 Effect of vector population

A single viruliferous adult female whitefly was able to transmit the virus and caused 15% YMD infection in the soybean plants whereas, the disease symptoms appeared in 27.3 days.

However, 10 viruliferous adult whiteflies/ plant transmitted 100% disease infection and the disease symptoms appeared in 18.4 days and it reduced to 13.9 and 13 days, when the vector population was 15 and 20 viruliferous whiteflies/ plant but, they did not differ significantly from each other. Vector population density was found to be directly and indirectly proportional to the MYMIV infection rate and the disease symptom expression period, respectively.

6.3.4 Retention period of virus in the vector

The vector was found to transmit the virus from 1st day of the serial transfer and the retention period was observed upto 15th day. The maximum disease infection was observed on the 2nd day of the serial transfer and thereafter the disease infection gradually declined with slight fluctuations on the 5th and 11th day of the serial transfer. The mortality of the vectors started from 11th day and attained maximum on 16th day of the serial transfer.

Correlation studies exhibited that the serial transfer days exhibited significant negative influence on MYMIV infection.

6.4 Conclusions

The first incidence of whitefly on soybean was observed on about 7 days old during *kharif* followed by summer and *rabi*. The incidence of whitefly during the *rabi* season was significantly lowest in comparison to summer and *kharif* and the later two were at par with each other. Maximum duration of stay of whitefly was recorded on the *rabi* crop followed by *kharif* and summer season crops. During *rabi* and summer, Max and Min T had positive and Morn RH had negative impact on whitefly population. The first incidence of YMD was recorded on 21 days old *kharif* and summer crops followed by *rabi* (*i.e.* 42 days old crop). Maximum incidence was attained in *kharif* when the crop age was about 2 months followed by summer (>2 month) and *rabi* (>3months). Early crop stage (about 1 month old crop) was found to be most vulnerable to whitefly and YMD incidence during *kharif* while during summer and *rabi*, it *was* the later stage *i.e.* >35 days old crop. During the *rabi* season the Max T, Min T, Evap, vector population and crop age of the same week having YMD incidence, preceding one and two weeks of YMD incidence, exhibited positive influence on YMD incidence. Further, during the summer season, the Max T, Min T, WS, Evap and crop age of same week having YMD incidence, preceding one and two weeks of YMD incidence, had shown significant positive influence on YMD incidence. During the *kharif* season the crop age and Min T of the same week having YMD, preceding one and two weeks of YMD incidence exhibited significant positive and negative influence on YMD incidence, respectively.

MYMIV DNA-A and B were first detected in the vector samples collected from 24.5±3.5, 14 and 7 DOC soybean crop during *rabi*, summer and *kharif* season, respectively. DNA-A and B were detected in the vector samples throughout the cropping season which ranged from 0 to 100, 20 to 100 and 25 to 90% during *rabi* summer and *kharif* season, respectively. MYMIV DNA-A and B were first detected in the leaf samples collected from 42±7, 14 and 17.5±3.5 DOC soybean during *rabi*, summer and *kharif*, season, respectively. The maximum virus infection in the leaf samples was recorded in 52±3.5 DOC during the *rabi* season, whereas in summer and *kharif* season it was 31.5±3.5 and 28±7 DOC, respectively.

In the *rabi* season during the period of maximum infection of virus in the leaf samples season, the Max T, Min T, Morn RH and evening were 24.7±3.7^{0}C, 11.7±0.4^{0}C, 88.5±0.5% and 57.5±17.5%, respectively, while during summer and *kharif* season it was 39.1±0.05^{0}C, 22±1.9^{0}C, 52±10%, 17.5±0.5%, 30.4±0.6^{0}C, 23.4±1^{0}C, 90% and 73.5±3.5%, respectively.

The transmission period of virus from the vector to the host plants was 14, 7 and 7 days during *rabi*, summer and *kharif* season, respectively. Whereas the disease symptom expression period during *rabi*, summer and *kharif* season was 7, 10.5±3.5 and 7 days, respectively.

The minimum acquisition access period (AAP) of 0.5 h was required by whitefly to transmit the MYMIV disease. At 12 h of acquisition feeding period, 100% disease infection was attained and the disease symptoms appeared in 20.6 days which further reduced to 18.9 days at 24 h of AAP.

At minimum inoculation period of 1 h the vector transmitted 10% YMD infection in the soybean plants and the first disease symptoms appeared in 24 days. At 18 h of IAP, 100% disease infection was recorded and the disease symptoms appeared in 17.5 days, which reduced to 15.8 days at 24 h IAP.

A single viruliferous adult female whitefly was able to transmit 15% YMD infection in the soybean plants and the disease symptoms appeared in 27.3 days. However, 10 viruliferous adult whiteflies/ plant caused 100% disease infection and the disease symptoms appeared in 18.4 days.

The maximum retention period in whitefly was upto 15th day, and the mortality started from 11th day and attained maximum on 16th day of the serial transfer.

6.5 Suggestions for further work

In view of the changing climatic conditions and the menace of the whitefly, *Bemisia tabaci* on most of the leguminous and vegetable crops, it has compelled to conduct studies on seasonal fluctuation of whitefly population on soybean and other host crops and their seasonal monitoring with yellow sticky traps consecutively for at least 3 years in order to establish a pest forecasting model for adopting eco-friendly and feasible management strategies.

Further studies on incidence of yellow mosaic disease (MYMIV and MYMV) should also be carried out on legume crops to generate information on its epidemiology, which will be helpful in decision making support system for the YMD forecasting model.

The studies on transmission of MYMIV through whitefly should be carried out thoroughly to understand the virus (MYMIV)-vector relationship in soybean which will be helpful to understand the behavior of vector, virus and host plants.

Some weeds also seem to play a major role as reservoir of virus during the off season of the crop, should also be addressed in the future studies. The molecular study should also be undertaken continuously to understand the base line of virus infectivity towards the characterization and identification of new emerging virus variants which will be helpful in formulation of integrated pest management programme.

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Seasonal population dynamics of whitefly (*Bemisia tabaci* Gennadius) in soybean

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Abstract
A trial was conducted to know the seasonal population dynamics of whitefly, *Bemisia tabaci* in soybean (*cv.* JS-335) and their relation to weather parameters during three consecutive seasons viz., *Rabi* (2014-15), summer (2015-16) and *Kharif* (2015-16). The population of adults whitefly were exhibited significantly positive correlation with maximum and minimum temperature (r= 54 and r= 0.58), morning and evening vapour pressure (r= 0.59 and r= 0.58) and evaporation (r= 0.56) whereas, negative correlation was expressed with morning RH% during *Rabi* season. Similarly during the summer season of soybean the maximum and minimum temperature (r= 0.74 and r= 0.65) and evaporation (r= 0.64) were showed significantly positive correlation with whitefly population while, morning RH% was exhibited negative. On the other hand, in *Kharif* season maximum temperature (r= 0.56), sunshine (r= 0.59) and evaporation (r= 0.59) were expressed significantly positive correlation whereas, wind speed and rainfall were negative on influence of whitefly population. Overall results revealed that weather parameters like temperature, RH%, sunshine and rainfall were played limiting factors for the buildup of whitefly population in soybean agro-ecosystem.

Keywords: Whitefly, *Bemisia tabaci*, soybean, population dynamics

1. Introduction
Soybean (*Glycine max* L.) is the main *Kharif* crop of the Madhya Pradesh state of India. The present area under soybean in the state is 6.31 million ha with production of 5.24 million tonnes and productivity 831 kg/ha [1]. It is world's most useful and cheapest sources of protein, vitamins, minerals, salts, carbohydrates and other ingredients which result it is known as Miracle bean and Golden bean. Its protein is rich in the valuable amino acid lycine (5%) which is generally deficient in most of the cereals. In Indian scenario, Madhya Pradesh alone contributes about 67 per cent area in which producing half of the total production of the India. Productivity of soybean is less than the potential yield of recommended varieties due to attack of different pests. About more than 150 insect pests have been reported on soybean crop in various parts of Madhya Pradesh [2]. Among them the whitefly, *Bemisia tabaci* Gennadius has became devastating insect pest which suck the phloem sap from the lower surface of leaves and also play as a vector for transmission of mungbean yellow mosaic virus disease in soybean, blackgram and greengram [3]. In Central India, yellow mosaic disease (YMD) of soybean, blackgram and greengram is caused by Mungbean Yellow Mosaic India Virus (MYMIV) [4-6]. It may cause 85–100% yield loss depending upon the susceptibility of the cultivar, time of infection, population of vector (*Bemisia tabaci*) and other favourable conditions [3]. In India, the annual monetary losses in legumes (soybean blackgram and mungbean) caused by YMD have been estimated to be approximately US $300 million per year [7]. Keeping the above facts it was planned to comprehensive study the influence of weather parameters on seasonal incidence of whitefly in soybean crop.

2. Materials and Methods
An investigation was carried out to study the seasonal population dynamics of whitefly in soybean crop (*cv.* JS-335) and their relation to weather parameters during three consecutive seasons viz., *Rabi* (2014-15), summer (2015-16) and *Kharif* (2015-16) at Breeding seed Production unit, Live Stock Farm, JNKVV, Jabalpur (MP), India. Soybean crop was grown as a test crops in *Rabi* and summer seasons only for experimental purpose to assess the seasonal fluctuations of whitefly population while this crop is usually grown in *Kharif* season.

2.1 Experimental layout
The plot size was kept 40x30m with the spacing of 45x10cm between the rows and plants. All the recommended agronomical practices like fertilizer, weeding operations were followed except the insect pest management.

2.2 Observation recorded
Observations on population of adult whiteflies were recorded weekly intervals on randomly ten selected plants of soybean by caging the individual plant with the help of cage till the availability of the insect or maturity of the crop whichever is earlier and their mean was calculated.

2.3 Statistical analysis
Statistical analysis of obtained data was studied through multiple correlation to find the seasonal population dynamics of whitefly on soybean with different weather parameters viz., temperature, Relative humidity, wind speed, sunshine hours, vapor pressure, evaporation and rainfall. Relationship between whitefly and different meteorological variables were subject to studied using simple correlation and regression.

3. Results and Discussion
3.1 Influence of weather parameters on activity of whitefly on *Rabi* soybean 2014-15
The results of seasonal population dynamics of whitefly in soybean field in *Rabi,* 2014-15 is presented in Table 1. Soybean crop was grown in *Rabi* season for experimental purpose to assess the population dynamics of whitefly. The population of whitefly was first observed from 49th SW (0.27 whiteflies/plant) which was gradually increased and reached at its peak on 8th SW (5 whiteflies/plant). During the peak period the maximum and minimum temperature were 30.6 ^{0}C and 12.0 ^{0}C, while morning and evening RH, wind speed, sunshine, morning and evening vapour pressure, evaporation and rainfall were 86% and 33%, 1.9km/h, 9.70 hrs, and 10.40 mm, 10.70mm, 3.30mm and 0.00mm, respectively. After that activity of whitefly population was somewhat gradually declined on 9th SW (2.5 whiteflies/plant) and again gradually increased on 10th SW (3.00whiteflies/plant), 11th SW (4.00 whiteflies/plant), 12th SW (4.47/plant) and declined with the increasing age of crop on 13th SW (2.50whiteflies/plant), respectively. Present results revealed that among the abiotic factors the temperature plays important role for oscillation of whitefly population and this was corroborated with the previous workers [8].

Table 1: Influence of weather parameters on activity of whitefly on *Rabi* soybean (2014-15)

SW	Whitefly/plant	Weather parameters									
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
49	0.27	28.7	8.0	88	24	2.5	8.7	7.8	6.3	3.1	0.0
50	0.50	29.0	11.8	89	52	2.6	6.2	10.3	8.0	1.7	3.2
51	0.60	25.3	5.6	86	32	2.2	7.6	6.4	6.4	1.8	0.0
52	0.70	23.8	4.8	87	32	2.1	8.5	6.4	6.1	2.0	0.0
1	0.60	20.5	11.7	90	61	3.8	6.5	10.4	10.4	1.1	37.7
2	0.93	22.1	5.3	87	38	2.1	8.5	6.8	7.4	1.4	0.0
3	1.30	22.2	5.3	91	37	2.6	8.3	7.3	7.3	1.7	0.0
4	0.90	21.0	12.1	89	75	3.3	3.7	11.1	12.6	0.9	10.2
5	1.77	22.5	8.7	85	44	2.7	9.8	8.3	9.0	1.7	10.8
6	2.40	24.2	10.2	88	52	4.5	7.1	9.5	11.6	2.7	14.4
7	3.00	26.8	10.4	88	40	2.8	9.1	9.4	10.7	2.7	6.2
8	5.00	30.6	12.0	86	33	1.9	9.7	10.4	10.7	3.3	0.0
9	2.50	26.7	14.5	85	54	3.2	6.8	12.0	12.6	2.4	64.8
10	3.00	28.0	12.0	85	39	2.9	9.5	10.4	11.2	3.3	0.0
11	4.00	26.8	15.2	87	54	3.6	6.0	13.2	13.3	1.7	23.6
12	4.47	31.8	13.8	80	26	2.2	10.3	11.4	9.5	4.0	0.0
13	2.50	35.1	17.4	78	23	3.3	8.5	13.2	9.3	4.9	0.0
Correlation (r)		0.54*	0.58*	-0.49*	-0.18	0.01	0.39	0.59*	0.58*	0.56*	0.04

*Significant (P=0.05), X_1-Maximum temp.(^{0}C), X_2-Minimum temp.(^{0}C), X_3-Morning RH%, X_4-Evening RH %, X_5-Wind speed (km/h), X_6-Sunshine (hrs), X_7-Morning vapour pressure (mm), X_8- Evening vapour pressure (mm), X_9 -Evaporation (mm) and X_{10}-Rainfall (mm).

Further correlation was studied between the mean whitefly population and weather parameters in which maximum and minimum temperature (r= 54 and r= 0.58), morning and evening vapour pressure (r= 0.59 and r= 0.58) and evaporation (r= 0.56) which were expressed significantly positive correlation, respectively, whereas morning RH% (r= -0.49) was exhibited negative correlation on influence of whitefly population. Regression equation of whitefly population with weather parameters viz., maximum temperature and minimum temperature, morning RH%, morning vapour pressure, evening vapour pressure and evaporation were exhibited as Y= -3.13+0.20x (R^2 =0.29), Y= - 0.37+0.23x (R^2 =0.33), Y= 20.97 - 0.22x (R^2 =0.24), Y= -1.74+0.39x (R^2 =0.33), Y= -1.47+ 0.37x (R^2 =0.33) and Y= 0.20+0.77x (R^2 =0.31), respectively. The equations of R^2 values were revealed that weather parameters which played role as density independent factors for fluctuation of whitefly population. Lapidot Moshe reported the life cycle progression of whitefly from egg to nymph and adult emergence is inevitably governed by temperature as a result the adult emergence does not occur when the temperature reached below 17 ^{0}C [9].

3.2 Influence of weather parameters on activity of whitefly on summer soybean 2015-16
Seasonal population dynamics of whitefly in summer soybean field during 2015-16 is shown in Table 2. The appearance of incremental adult whiteflies populations were ranged from 2.30 to 14.50 whiteflies/plant. The lowest mean population of whitefly was recorded 2.30 whiteflies/plant in 14th SW. During this week maximum and minimum temperature were 35.4 ^{0}C and 19 ^{0}C, whereas morning and evening RH, wind speed, sunshine, morning and evening vapour pressure, evaporation and rainfall were 55% and 23%, 5.3 km/h, 9.3 hrs, 11.3mm, 9.6mm, 6.9mm and 0.00mm, respectively. After that activity of whitefly population was somewhat gradually increased and reached at peak on 21st SW (14.50whiteflies/plant) when received favourable weather conditions.

Table 2: Influence of weather parameters on activity of whitefly on summer soybean (2015-16)

SW	Whitefly/plant	Weather parameters									
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
14	2.30	35.4	19.0	55	23	5.3	9.3	11.3	9.6	6.9	0.0
15	4.80	33.6	18.9	75	35	5.1	8.1	14.3	11.6	5.3	12.4
16	6.20	37.4	20.5	64	18	3.9	9.2	15.5	8.9	6.6	1.0
17	9.00	39.2	23.9	42	17	6.3	9.4	11.5	8.9	8.1	0.0
18	12.20	40.4	23.5	44	14	4.7	8.3	12.0	7.4	7.4	0.0
19	10.50	41.9	24.0	37	14	4.9	9.0	11.4	7.9	8.4	4.4
20	12.00	40.2	25.8	51	23	5.8	7.5	15.8	11.5	7.7	0.0
21	14.50	42.8	27.5	37	16	6.9	9.4	13.2	10.2	10.9	6.2
22	8.60	43.0	27.0	40	17	5.4	8.9	13.1	10.2	9.5	0.0
23	7.00	41.6	28.7	46	20	6.2	8.3	16.6	12.4	8.9	0.0
Correlation (r)		0.74*	0.65*	-0.66*	-0.56	0.32	-0.12	-0.05	-0.22	0.64*	-0.05

*Significant (P=0.05), X_1-Maximum temp.(^{0}C), X_2-Minimum temp.(^{0}C), X_3-Morning RH%, X_4-Evening RH %, X_5-Wind speed (km/h), X_6-Sunshine (hrs), X_7-Morning vapour pressure (mm), X_8- Evening vapour pressure (mm), X_9 -Evaporation (mm) and X_{10}-Rainfall (mm)

During this week the maximum and minimum temperature were 42.8 ^{0}C and 27.5 ^{0}C, whereas morning and evening RH, wind speed, sunshine, morning and evening vapour pressure, evaporation and rainfall were 37% and 16%, 6.9 km/h, 9.4 hrs, 13.2mm, 10.2mm 10.9mm and 6.2mm, respectively. The whitefly population was started declined with increasing age of the crops on 22nd (8.60whiteflies/plant) and 23rd SW (7.00whiteflies/plant), respectively. The correlation between the mean whitefly population and weather parameters in which maximum and minimum temperature (r= 0.74 and r= 0.65), and evaporation (r= 0.64) were expressed significantly positive, while morning RH has exhibited negative correlation (r= -0.66) and other parameters were found statistically non-significant. Regression equation of whitefly population with weather parameters viz., maximum temperature, minimum temperature and evaporation were observed as Y= -25.91+0.88x (R^2 =0.55), Y= -7.97+0.70x (R^2 =0.43) and Y = -3.27+1.50x (R^2 =0.41), respectively, while morning RH% was Y =18.42-0.20x (R^2 =0.43). The R^2 values revealed that fluctuation of whitefly were governed by weather parameters. Gupta *et al.* also stated that temperature was expressed positive correlation, while relative humidity and rainfall influenced negative correlation on population of whitefly on cotton [10]

3.3 Influence of weather parameters on activity of whitefly on *Kharif* soybean 2015-16

Seasonal population dynamics of whitefly in soybean field in *Kharif* 2015 is shown in Table 3. Population of adult whitefly was ranged from 1.77 to 13.40whiteflies/plant. The lowest population of whiteflies (1.77/plant) was recorded on 29th SW. During this SW the maximum and minimum temperature were 31.3 ^{0}C and 24.2 ^{0}C, whereas morning and evening RH, wind speed, sunshine, morning and evening vapour pressure, evaporation and rainfall were 89% and 70%, 5.1km/h, 2.8 hrs, 22.5mm, 22.9mm, 3.6mm and rainfall 72.8mm, respectively. After that activity of whitefly population was gradually increased and reached at peak on 32nd SW when the favourable weather parameters were occurred. During this SW the maximum population of whiteflies (6.00/plant) was recorded. During this SW the maximum and minimum temperature were 31.2 ^{0}C and 24.2 ^{0}C, whereas morning and evening RH, wind speed, sunshine, morning and evening vapour pressure, evaporation and rainfall were 91% and 69%, 3.7 km/h, 4.6 hrs, 23. 1mm, 23.7mm, 3.6mm and 14mm, respectively. After that the population of whitefly was again little bit declined and reached at peak on 37th SW (13.40whiteflies/plant). During this highest peak the maximum and minimum temperature were 33.5 ^{0}C and 23.1 ^{0}C, while morning and evening RH, wind speed, sunshine, morning and evening vapour pressure, evaporation and rainfall were 91% and 55%, 3.1 km/h, 8.4hrs, 23.3mm, 21.2mm, 4.0mm and 3.4mm, respectively. After that it was gradually declined as the increased the age of crop and remained up to 41st SW (6.4 whiteflies/plant) although temperature and relative humidity was increased. During this week the maximum and minimum temperature were 35.1 ^{0}C and 17.9 ^{0}C, whereas morning and evening RH, wind speed, sunshine, morning and evening vapour pressure, evaporation and rainfall were 88% and 31%, 2.2 km/h, 9.5hrs, 16.3mm, 12.2mm, 3.8mm and 0.0mm, respectively.

Table 3: Influence of weather parameters on activity of whitefly on *Kharif* soybean (2015-16)

SW	Whitefly/plant	Weather parameters									
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
29	1.77	31.5	24.2	89	70	5.1	2.8	22.5	22.9	3.6	72.8
30	2.50	30.6	23.5	87	67	5.4	4.5	21.5	20.8	3.0	84.7
31	2.40	29.8	23.6	90	70	8.3	4.7	21.3	20.2	3.4	149.4
32	6.00	31.2	24.2	91	69	3.7	4.6	23.1	23.7	3.6	14
33	3.40	31.2	24.5	91	73	6.1	3.0	22.8	23.3	2.9	116.8
34	5.20	31.3	23.6	88	64	6.5	7.4	21.6	21.3	3.6	9.4
35	6.60	30.4	22.9	93	76	4.9	3.0	21.8	22.7	3.8	104.6
36	11.20	32.2	24.2	87	57	3.5	6.7	21.5	20.8	3.4	8.2
37	13.40	33.5	23.1	91	55	3.1	8.4	22.3	21.2	4.0	3.4
38	9.00	32	23.7	92	64	5.5	5.6	22.7	21.7	4.4	70.2
39	8.5	32.6	21.1	84	45	4.2	9.2	18.4	16.6	3.8	0.0
40	7.50	33.1	19.5	88	35	2.1	9.3	18.3	14.3	3.7	0.0
41	6.4	35.1	17.9	88	31	2.2	9.5	16.3	12.2	3.8	0.0
Correlation (r)		0.56*	-0.18	-0.005	-0.42	-0.59*	0.59*	-0.11	-0.18	0.59*	-0.63*

*Significant (P=0.05), X_1-Maximum temp.(^{0}C), X_2-Minimum temp.(^{0}C), X_3-Morning RH%, X_4-Evening RH%, X_5-Wind speed (km/h), X_6-Sunshine (hrs), X_7-Morning vapour pressure (mm), X_8- Evening vapour pressure (mm), X_9 -Evaporation (mm) and X_{10}-Rainfall (mm)

Whitefly prefers to suck the phloem sap from the succulent part of the plant and as the plant become older its dry matter accumulation is increased with the age of the plant and thus reduces population of whitefly and its infestation as well [11-12]. Selvaraj and Ramesh observed maximum temperature ranging from 26-35 ^{0}C, RH 67 to 84%, wind velocity 6.3km/h, sunshine 9.4 hrs and evaporation 52.20 mm were found to be congenial for the built up of whitefly population on cotton [13]. Though, this result may vary with the findings of other workers because of ecological and different weather conditions, cropping pattern and season, occurrence of natural enemies of the whitefly.

The correlation coefficient was expressed significantly positive between the mean whitefly population and maximum temperature (r= 0.56), sunshine (r= 0.59) and evaporation (r= 0.59), whereas wind speed (r= -0.58) and rainfall (r= -0.63) were significantly negative influenced to the activity of whitefly. Although, minimum temperature, both morning and evening RH were exhibited negative correlation (r=0.005 and r= 0.420) but statistically non-significant. Mean temperature around 26^{0}C was most conducive for the population build-up of whitefly, *B. tabaci* soybean.

Regression equation of whitefly population with weather parameters viz., maximum, temperature, wind speed, sunshine and evaporation were calculated as Y = - 37.25+1.37x (R^2 =0.31), Y = 11.85-1.16x (R^2 =0.34) and Y = 1.46+0.83x (R^2 =0.35), Y = - 12.47+5.23x (R^2 =0.34), respectively, while rainfall was Y = 8.47+-0.04x (R^2 =0.39). All R^2 values indicated that population of whitefly actively fluctuate due to the contribution of environmental factors. Earlier researchers reported the population of adult whiteflies showed a significant positive association with temperature and sunshine while negative correlation with rainfall [14]. Shrivastva and Prajapati reported that maximum temperature was exhibited significantly positive (r= 0.82), whereas mean RH (r= -0.83) and rainfall (r= -0.56) showed negative influence on whitefly population in blackgram (*Vigna mungo*) [15], whereas, temperature (r= 0.57) and relative humidity (r=0.77) exhibited significant positive correlation whereas rainfall (r=0.29) did not show significant correlation with whitefly population on cotton [16]. Similar results was also reported that maximum temperature and evaporation exhibited significantly positive correlation while, evening relative humidity and rainfall were expressed negative correlation on influence of whitefly population of soybean[17].

4. Conclusion

The present experiment in which soybean was grown in three consecutive seasons to assess the seasonal population dynamics of whitefly. It provides basic information for population dynamics of whitefly during *Rabi,* summer and *Kharif* seasons. Seasonal population fluctuations of whitefly on legume crops particularly soybean, blackgram and greengram are greatly influenced by abiotic factors and peak population levels are observed during consecutively grown crop of soybean. The statistically significant correlation values indicated that occurrence of whitefly population as its outbreak on soybean crop was due to the prevailing ecological conditions and impact of climate change. This experiment will support in the formulation of insect pest monitoring system and sustainable integrated pest management module.

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Molecular identification of Mungbean yellow mosaic India virus (MYMIV) from whitefly and soybean in Jabalpur district of Madhya Pradesh, Central India

RS Marabi, SB Das, N Tripathi, AK Bhowmick, R Pachori and Vibha

Abstract
Yellow mosaic disease caused by genus Begomovirus which is transmitted through whitefly, *Bemisia tabaci* has become an important constraint for legume production particularly in soybean, urdbean, mungbean and other bean crops of India. The present investigation was performed with the aim to identify Mungbean yellow mosaic India virus (MYMIV) infection in soybean as well as whitefly with the use of coat protein (CP) primer. The genomic DNA templates from both were extracted and amplified with CP primer. DNA templates from yellow mosaic symptomatic plants and carrier whiteflies were amplified with a band size of ~750bp. The present study confirms the utility of CP primers for the detection of MYMIV which is found to be most prevalent yellow mosaic disease in soybean crop at Jabalpur district of Madhya Pradesh, Central India.

Keywords: Soybean, Coat protein, MYMIV, Whitefly, *Bemisia tabaci,* Begomovirus

1. Introduction
Yellow mosaic diseases (YMD) are major biotic constraints on the productivity of legume crops in India. YMD in soybean was first reported from the northern region of the country, had spread to different parts of Central India where large acreage is under soybean (*Glycine max*) cultivation with yield losses of 21–70% (Dasgupta *et al.*, 2003) [1].YMD caused by Mungbean yellow mosaic India virus (MYMIV) is one of the important constraints to soybean, urdbean (*Vigna mungo*) and mungbean (*Vigna radiata*) production in Central India (Ramesh *et al.* 2016) [2]. MYMIV is transmitted by the whitefly, *Bemisia tabaci* Gennadius infect the legumes such as soybean, urdbean and mungbean reported by Govindan *et al.*[3] and Marabi *et al.*[4] In India, the annual monetary losses in legumes (soybean, urdbean and mungbean) caused by YMD have been estimated to be approximately US $300 million per year (Varma *et al.* 2003) [5]. Since last few decades it has been experienced that the total cultivated area of soybean is declined continuously due to severe incidence of yellow mosaic disease. Information on the alternative weed hosts of MYMIV is limited which need to be addressed to unveil the reasons. Although a single whitefly is able to acquire virus and transmit to plants. Female *B. tabaci* is more active and efficient to transmit virus than male. Many weeds in and around the agricultural field throughout the year are often seen with YMD symptoms and occurrence of whiteflies are also observed on many weed species. Whiteflies take shelters on alternative hosts (weeds) which are found to be major and sometime act as transient reservoir of MYMIV after harvesting the main crops and carry over to the next season. Therefore, the current study was taken up to confirm the identity of the virus causing YMD in soybean as well as its vector at molecular level.

2. Material and Methods
2.1 Culturing of insect vector and virus source
Culturing of vector (*B. tabaci*) and virus sources were maintained in insect proof net house (Size: 50 mesh) following the methodology proposed by Aidawati *et al.* (2002) [6]. Healthy non-viruliferous colonies of whiteflies were maintained on healthy soybean plants (cv. JS 335) which were used for MYMIV transmission studies. For inoculation study, single healthy seedling of soybean was grown in each earthen pot.

Simultaneously soybean plants showing typical yellow mosaic disease symptoms were collected from the soybean field which was confirmed as MYMIV by molecular studies through PCR technique and were maintained as virus source.

2.2 Virus-vector relationship

A known number of healthy non-viruliferous adult female whiteflies were released on MYMIV-infected soybean plants and was given 24 hrs to acquire virus *i.e.* acquisition access period (AAP). After the AAP, the whiteflies were re-collected individually with the help of aspirator and transferred them on 7-14 days old healthy soybean plants for 24 hrs *i.e.* inoculation access period (IAP) for transmitting the virus. Ten adult female whiteflies per plant were used and replicated it ten times. After inoculation the whiteflies were completely removed and plants were maintained under insect-free condition for development of disease symptoms. Percentage of virus infection (*i.e.* percent disease incidence) was computed from inoculated test plants which were expressed disease symptoms.

2.3 Isolation of DNA from whitefly sample

Whiteflies were collected by using the aspirator from experimental field and preserved in 100 percent acetone at 4°C until use. A total of 30µl of STE buffer [100mM NaCl, 1mM EDTA(pH8.0), 10mM Tris-HCl(pH8.0)] was taken in a microcentrifuge tube and a single whitefly was introduced in it using fine pointed paint brush (Zero number brush- Camel). The whitefly was crushed using micro pestle to make homogenate solution and 2 µl of proteinase-K (10mg/1ml) was added to the homogenate and mixed thoroughly. Homogenate containing microcentrifuge tubes were incubated at 55^{0}C for 30 min in heating block. Microcentrifuge tubes were then incubated at 90 ^{0}C for 5 min using another heating block. Microcentrifuge tubes were centrifuged slightly to collect the liquid on the bottom. Resultant DNA solution was stored in refrigerator until further activities.

2.4 Isolation of DNA from soybean leaf sample

Leaf sample of soybean (cv. JS 335) was collected from the field and individually kept in sterilized polythene bag containing zip. After bringing the samples in laboratory 100mg leaf sample was marked and wrapped in aluminum foil and then frozen in liquid nitrogen before storing in -80 ^{0}C. DNA from soybean leaf samples was isolated using DNeasy Plant Mini Kit (Qiagen) and stored in refrigerator until its use.

2.4 PCR amplification

Molecular markers were designed for DNA-A (CP) genomes of mungbean yellow mosaic India virus (MYMIV): DNA-A (CP) forward primer – 5'ACACGGATCCGTTGCATACACAGGATTTG3'; reverse primer – 5'ACACGAGCTCCTCTACCCCGATATCGAATG3'. PCR was carried out with genomic DNA using molecular markers in Bio-Rad Thermal cycler. The reaction was carried out in 25 µl volumes, which contains 1.0µl (25ng) of soybean genomic DNA, 1.0µl (2.5pmole) of forward and reverse primers each, 1.0µl (2.0mM) of dNTPs, 1.0µl of Taq buffer (10X), 1.0µl of $MgCl_2$ (25mM) and 1 units of *Taq* polymerase. All the chemicals and plasticwares used were obtained from Genei and Tarsons Company, respectively. PCR Programme was standardized to carry out amplification with DNA-A genome specific primer as mentioned in the Table 1. The amplified products were resolved on 1.0% agarose gel and visualized under Syngene gel documentation system.

Table 1: PCR programme

Steps followed in Thermal cycler	Temperature in °C for one cycle	Time for one cycle
Marker	CP	
Step 1	94 °C	1 min.
Step 2	94 °C	20 sec.
Step 3	56 °C	20 sec.
Step 4	72 °C	1 min.
Step 2 – Step 4 are repeated for 30 cycles		
Step 5	72 °C	3 min.
Step 6	Hold at 4 °C	

3. Results and Discussion

Improved frequency of whitefly outbreaks due to the expansion of insecticide resistance in whitefly has increased the incidence of MYMIV and therefore needs for resistant cultivars (Ahmad *et al.*, 2010) [7]. Identification of MYMIV and whitefly resistant soybean cultivars is an environmentally compatible and effective control method (Martin and Fereres, 2003) [8]. In the present study, an evaluation of MYMIV infection on soybean genotypes and its vector whitefly (*B. tabaci*) was carried out under natural infection in field and in the net-house using whiteflies inoculations.

3.1 Transmission

Yellow mosaic symptom was first recorded after 15 days of inoculation. The expression of disease symptoms was produced in the form of typical yellow specks and golden mosaic on the leaves of soybean test plant (Figure 1B). After inoculation, all soybean test plants were found to be 100 per cent yellow mosaic disease symptoms within 15-21 days similar to those seen in the field indicating that the causal agent of virus was transmitted by the whiteflies in same manner. Present finding is accordance with the result of Usharani *et al.* (2004) [9] who studied whitefly inoculation in the glass house on soybean (cv. Bragg). Gazala *et al.* (2013) [10] also reported that at 18 hrs of AAP and 24 hrs of IAP the MYMIV symptoms was developed after 20 days of inoculation in the form of mild scattered yellow specks in the leaves soybean (cv. JS 335) plants.

3.2 Amplification and data analysis

Because of its high degree of conservation, the coat protein ORF (CP) is the only begomovirus sequence approved by the International Committee on Taxonomy of Viruses for ascertaining the identity of a begomovirus (Mayo and Pringle, 1998) [11] it was used to amplify template DNA isolated from whitefly and soybean plants both.

PCR tests yielded amplified DNA fragments of the expected size ~750 bp, of MYMIV in the symptomatic leaf samples of soybean collected from the field as well as in the whitefly. Gel photographs of PCR amplified products of all the samples

are shown in Figures 2 and 3, respectively. The findings indicate that the primer CP specific to coat protein gene is important for detection of MYMIV infection in plants and from viruliferous whiteflies.

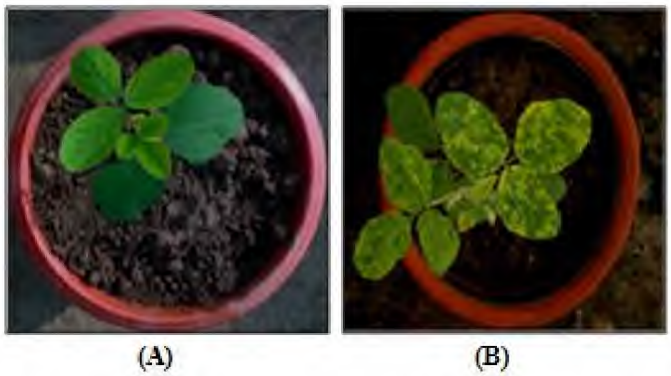

Fig 1: (A) Healthy soybean plant (B) MYMIV symptoms on soybean plant after inoculation through viruliferous whiteflies

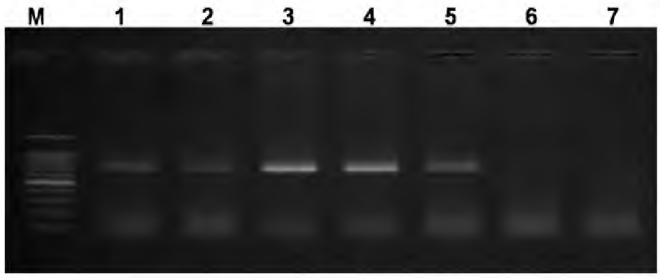

Fig 2: PCR amplifications of whitefly DNA using CP primer. 1-5 whiteflies collected form MYMIV infected soybean plants and 6-7 whiteflies collected form healthy soybean plants, M=100bp DNA ladder

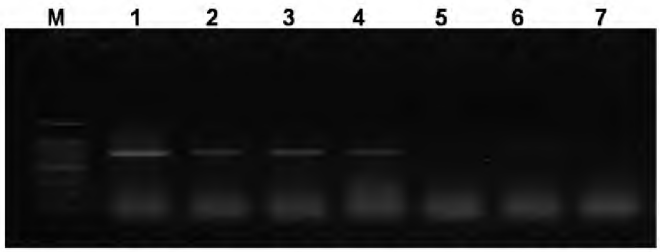

Fig 3: PCR amplifications of soybean leaf DNA using CP Primer. 1-6 MYMIV infected soybean leaves and 7 healthy soybean leaf, M=100bp DNA ladder

4. Acknowledgement

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Appendix I: Weekly meteorological data of Experimental field J.N.K.V.V. Jabalpur (M.P.) during the period of study and crop age (2014 and 2015)

Year		Dates	Crop age (days)			Temperature (°C)		RH (%)		Wind Speed (km/hr)	Sunshine (hrs)	Vapour Pressure (mm)		Evapo. (mm)	Rainfall (mm)
	SW	From - To	*Rabi*	Summer	*Kharif*	Max.	Min.	Mor.	Eve.			Mor.	Eve.		
2014	47	19 - 25 Nov.	-	-	-	27.90	8.90	82.00	20.00	1.80	8.60	8.10	6.50	2.50	0.00
	48	26 Nov. - 02 Dec.	-	-	-	28.40	10.20	85.00	24.00	2.10	8.60	9.10	7.20	2.70	0.00
	49	03 - 09 Dec.	7	-	-	28.70	8.00	88.00	24.00	2.50	8.70	7.80	6.30	3.10	0.00
	50	10 - 16 Dec.	14	-	-	29.00	11.80	89.00	52.00	2.60	6.20	10.30	8.00	1.70	3.20
	51	17 - 23 Dec.	21	-	-	25.30	5.60	86.00	32.00	2.20	7.60	6.40	6.40	1.80	0.00
	52	24 - 31 Dec.	28	-	-	23.80	4.80	87.00	32.00	2.10	8.50	6.40	6.10	2.00	0.00
2015	1	01 - 07 Jan.	35	-	-	20.50	11.70	90.00	61.00	3.80	6.50	10.40	10.40	1.10	37.70
	2	08 - 14 Jan.	42	-	-	22.10	5.30	87.00	38.00	2.10	8.50	6.80	7.40	1.40	0.00
	3	15 - 21 Jan.	49	-	-	22.20	5.30	91.00	37.00	2.60	8.30	7.30	7.30	1.70	0.00
	4	22 - 28 Jan.	56	-	-	21.00	12.10	89.00	75.00	3.30	3.70	11.10	12.60	0.90	10.20
	5	29 Jan. - 04 Feb.	63	-	-	22.50	8.70	85.00	44.00	2.70	9.80	8.30	9.00	1.70	10.80
	6	05 - 11 Feb.	70	-	-	24.20	10.20	88.00	52.00	4.50	7.10	9.50	11.60	2.70	14.40
	7	12 - 18 Feb.	77	-	-	26.80	10.40	88.00	40.00	2.80	9.10	9.40	10.70	2.70	6.20
	8	19 - 25 Feb.	84	-	-	30.60	12.00	86.00	33.00	1.90	9.70	10.40	10.70	3.30	0.00
	9	26 Feb. - 04 Mar.	91	-	-	26.70	14.50	85.00	54.00	3.20	6.80	12.00	12.60	2.40	64.80
	10	05 - 11 Mar.	98	-	-	28.00	12.00	85.00	39.00	2.90	9.50	10.40	11.20	3.30	0.00
	11	12 - 18 Mar.	105	-	-	26.80	15.20	87.00	54.00	3.60	6.00	13.20	13.30	1.70	23.60
	12	19 - 25 Mar.	112	-	-	31.80	13.80	80.00	26.00	2.20	10.30	11.40	9.50	4.00	0.00
	13	26 Mar. - 01 Apr.	119	-	-	35.10	17.40	78.00	23.00	3.30	8.50	13.20	9.30	4.90	0.00
	14	02 - 08 Apr.	-	7	-	35.40	19.00	55.00	23.00	5.30	9.30	11.30	9.60	6.90	0.00
	15	09 - 15 Apr.	-	14	-	33.60	18.90	75.00	35.00	5.10	8.10	14.30	11.60	5.30	12.40
	16	16 - 22 Apr.	-	21	-	37.40	20.50	64.00	18.00	3.90	9.20	15.50	8.90	6.60	1.00
	17	23 - 29 Apr.	-	28	-	39.20	23.90	42.00	17.00	6.30	9.40	11.50	8.90	8.10	0.00
	18	30 Apr. - 06 May	-	35	-	40.40	23.50	44.00	14.00	4.70	8.30	12.00	7.40	7.40	0.00

Year		Dates	Crop age (days)			Temperature (°C)		RH (%)		Wind Speed (km/hr)	Sunshine (hrs)	Vapour Pressure (mm)		Evapo. (mm)	Rainfall (mm)
	SW	From - To	*Rabi*	Summer	*Kharif*	Max.	Min.	Mor.	Eve.			Mor.	Eve.		
	19	07 - 13 May	-	42	-	41.90	24.00	37.00	14.00	4.90	9.00	11.40	7.90	8.40	4.40
	20	14 - 20 May	-	49	-	40.20	25.80	51.00	23.00	5.80	7.50	15.80	11.50	7.70	0.00
	21	21 - 27 May	-	56	-	42.80	27.50	37.00	16.00	6.90	9.40	13.20	10.20	10.90	6.20
	22	28 May - 03 Jun.	-	63	-	43.00	27.00	40.00	17.00	5.40	8.90	13.10	10.20	9.50	0.00
	23	04 -10 Jun.	-	70	-	41.60	28.70	46.00	20.00	6.20	8.30	16.60	12.40	8.90	0.00
	24	11 -17 Jun.	-	-	-	36.50	25.80	72.00	49.00	5.60	4.20	20.50	18.20	5.60	16.60
	25	18 - 24 Jun.	-	-	-	37.80	26.30	73.00	52.00	7.20	7.00	20.90	20.10	6.00	1.60
	26	25 Jun. - 01 Jul.	-	-	-	32.80	23.60	84.00	61.00	7.70	4.60	21.10	20.80	3.50	83.30
	27	02 - 08 Jul.	-	-	-	33.80	24.70	78.00	55.00	8.30	5.90	20.60	20.70	4.50	51.00
	28	09 - 15 Jul.	-	-	-	30.40	24.20	91.00	74.00	7.30	6.80	23.10	23.30	3.00	203.20
	29	16 - 22 Jul.	-	-	7	31.50	24.20	89.00	70.00	5.10	2.80	22.50	22.90	3.60	72.80
	30	23 - 29 Jul.	-	-	14	30.60	23.50	87.00	67.00	5.40	4.50	21.50	20.80	3.00	84.70
	31	30 Jul. - 05 Aug.	-	-	21	29.80	23.60	90.00	70.00	8.30	4.70	21.30	20.20	3.40	149.40
	32	06 - 12 Aug.	-	-	28	31.20	24.20	91.00	69.00	3.70	4.60	23.10	23.70	3.60	14.00
	33	13 - 19 Aug.	-	-	35	31.20	24.50	91.00	73.00	6.10	3.00	22.80	23.30	2.90	116.80
	34	20 - 26 Aug.	-	-	42	31.30	23.60	88.00	64.00	6.50	7.40	21.60	21.30	3.60	9.40
	35	27 Aug. - 02 Sep.	-	-	49	30.40	22.90	93.00	76.00	4.90	3.00	21.80	22.70	3.80	104.60
	36	03 - 09 Sep.	-	-	56	32.20	24.20	87.00	57.00	3.50	6.70	21.50	20.80	3.40	8.20
	37	10 - 16 Sep.	-	-	63	33.50	23.10	91.00	55.00	3.10	8.40	22.30	21.20	4.00	3.40
	38	17 - 23 Sep.	-	-	70	32.00	23.70	92.00	64.00	5.50	5.60	22.70	21.70	4.40	70.20
	39	24 - 30 Sep.	-	-	77	32.60	21.10	84.00	45.00	4.20	9.20	18.40	16.60	3.80	0.00
	40	01 - 07 Oct.	-	-	84	33.10	19.50	88.00	35.00	2.10	9.30	18.30	14.30	3.70	0.00
	41	08 - 14 Oct.	-	-	91	35.10	17.90	88.00	31.00	2.20	9.50	16.30	12.20	3.80	0.00
	42	15 - 21 Oct.	-	-	-	34.30	19.00	86.00	36.00	2.40	9.20	17.00	14.10	3.70	0.00
	43	22 - 28 Oct.	-	-	-	33.30	18.40	87.00	47.00	2.60	6.90	16.60	15.00	3.00	0.00

Appendix II: Weekly meteorological data of Experimental field J.N.K.V.V. Jabalpur (M.P.) during the period of study and crop age (2015 and 2016)

Year		Dates	Crop age (days)			Temperature (°C)		RH (%)		Wind Speed (km/hr)	Sunshine (hrs)	Vapour Pressure (mm)		Evapo. (mm)	Rainfall (mm)
	SW	From - To	*Rabi*	Summer	*Kharif*	Max.	Min.	Mor.	Eve.			Mor.	Eve.		
2015	51	17 - 23 Dec.	-	-	-	24.10	7.00	86.00	37.00	2.80	7.00	7.30	8.10	2.00	0.00
	52	24 - 31 Dec.	-	-	-	24.20	5.40	91.00	25.00	1.50	8.60	7.00	5.80	2.00	0.00
2016	1	01 - 07 Jan.	7	-	-	27.50	7.90	88.00	27.00	1.80	8.50	8.00	7.40	1.80	0.00
	2	08 - 14 Jan.	14	-	-	26.70	8.00	81.00	32.00	1.70	7.70	7.60	8.00	2.10	0.00
	3	15 - 21 Jan.	21	-	-	22.20	11.50	92.00	65.00	3.50	5.40	10.60	11.80	1.30	12.20
	4	22 - 28 Jan.	28	-	-	23.30	4.20	94.00	29.00	2.30	9.60	6.40	6.70	1.90	0.00
	5	29 Jan.- 04 Feb.	35	-	-	27.70	9.10	92.00	35.00	2.80	9.30	8.90	9.30	2.50	0.00
	6	05 - 11 Feb.	42	-	-	26.40	8.40	84.00	34.00	3.20	8.30	8.10	8.90	2.80	0.00
	7	12 - 18 Feb.	49	-	-	28.50	11.30	88.00	40.00	3.30	6.90	10.50	11.90	2.60	0.00
	8	19 - 25 Feb.	56	-	-	30.20	11.80	90.00	32.00	2.70	7.40	11.00	11.50	3.00	0.00
	9	26 Feb. -04 Mar.	63	-	-	30.50	13.40	85.00	34.00	3.30	8.50	10.70	11.00	2.80	0.00
	10	05 - 11 Mar.	70	7	-	31.90	17.00	88.00	47.00	3.50	8.00	14.10	15.30	3.40	29.60
	11	12 - 18 Mar.	77	14	-	30.90	15.00	85.00	37.00	4.10	8.70	13.00	11.20	3.90	6.50
	12	19 - 25 Mar.	84	21	-	34.50	14.10	67.00	18.00	3.30	10.20	10.50	7.30	5.30	0.00
	13	26 Mar. - 01 Apr.	91	28	-	35.80	16.40	78.00	17.00	2.30	10.00	12.90	7.10	4.70	8.00
	14	02 - 08 Apr.	98	35	-	39.10	20.10	62.00	18.17	3.00	9.10	13.60	9.10	6.50	0.00
	15	09 - 15 Apr.	105	42	-	38.90	19.60	56.00	12.00	3.80	10.20	12.20	6.50	7.70	0.00
	16	16 - 22 Apr.	-	49	-	41.10	21.90	48.00	12.00	5.00	10.50	11.70	7.10	8.80	0.00
	17	23 - 29 Apr.	-	56	-	40.20	20.90	46.00	11.00	5.10	10.40	11.60	6.20	9.40	0.00
	18	30 Apr. - 06 May	-	63	-	41.50	22.70	38.00	14.00	6.90	9.80	10.90	7.80	10.70	3.20
	19	07 - 13 May	-	70	-	39.70	24.00	44.00	19.00	4.40	8.80	12.90	10.50	8.70	0.00
	20	14 - 20 May	-	77	-	43.90	27.60	36.00	15.00	5.60	9.50	13.30	9.60	10.40	0.00

	21	21 - 27 May	-	84	-	41.10	26.80	54.00	38.00	9.10	8.10	17.50	16.20	9.80	26.80
	22	28 May - 03 Jun.	-	91	-	39.80	24.60	62.00	27.00	6.30	8.90	18.90	14.50	6.50	15.20
	23	04 -10 Jun.	-	-	-	41.90	26.70	55.00	24.00	7.30	9.00	18.30	14.30	8.60	7.80
	24	11 -17 Jun.	-	-	-	40.10	27.60	55.00	32.00	8.70	8.10	18.20	16.40	8.70	2.40
	25	18 - 24 Jun.	-	-	-	36.90	25.30	78.00	50.00	5.80	5.70	22.30	21.50	5.50	48.20
	26	25 Jun. - 01 Jul.	-	-	-	35.80	24.90	87.00	55.00	5.40	6.60	24.00	22.70	5.10	60.60
	27	02 - 08 Jul.	-	-	7	29.50	23.10	94.00	81.00	8.60	2.60	22.30	23.70	2.30	373.30
	28	09 - 15 Jul.	-	-	14	31.10	24.50	93.00	79.00	6.40	3.00	23.50	23.80	3.00	83.60
	29	16 - 22 Jul.	-	-	21	30.40	24.00	91.00	69.00	7.50	3.90	22.40	22.70	3.70	63.60
	30	23 - 29 Jul.	-	-	28	31.70	24.00	91.00	67.00	4.50	4.70	23.20	22.50	3.70	61.80
	31	30 Jul. - 05 Aug.	-	-	35	31.00	23.30	91.00	77.00	5.00	2.90	22.80	24.20	3.30	196.40
	32	06 - 12 Aug.	-	-	42	28.60	23.60	93.00	82.00	6.80	1.30	22.20	22.80	2.70	132.80
	33	13 - 19 Aug.	-	-	49	27.00	23.00	93.00	91.00	7.00	0.00	21.30	22.90	2.30	182.90
	34	20 - 26 Aug.	-	-	56	28.80	22.10	90.00	76.00	5.90	6.10	20.60	22.20	2.00	263.20
	35	27 Aug. - 02 Sep.	-	-	63	32.20	23.70	90.00	70.00	4.30	6.10	22.30	23.30	3.80	35.20
	36	03 - 09 Sep.	-	-	70	30.60	23.00	87.00	63.00	6.90	4.50	20.60	20.60	3.80	17.60
	37	10 - 16 Sep.	-	-	77	31.70	23.60	89.00	65.00	4.50	1.90	22.40	22.00	3.50	18.00
	38	17 - 23 Sep.	-	-	84	33.00	23.90	92.00	64.00	3.50	6.70	22.90	23.30	3.30	3.80
	39	24 - 30 Sep.	-	-	91	29.90	23.50	94.00	83.00	4.00	4.60	22.30	22.60	3.00	52.40
	40	01 - 07 Oct.	-	-	-	31.90	23.90	93.00	64.00	3.00	7.30	22.10	22.10	3.00	24.20
	41	08 - 14 Oct.	-	-	-	31.50	21.30	88.00	51.00	4.20	8.00	18.90	17.20	3.20	0.00

Appendix III

List of chemicals

S. No.	Chemicals	Manufacturer/ Make
1.	Agarose	Sigma
2.	Chloroform	Rankem
3.	dNTP's (Deoxy Nucleotide Triphosphate)	Merck Millipore
4.	Ethanol (70 %)	Merck Millipore
5.	Ethidium bromide (10mg/ml)	Merck Millipore
6.	Ethylene Diamine Tetra Acetic Acid (EDTA)	Merck Millipore
7.	Glacial acetic acid	Rankem
8.	Isoamyl alcohol	Rankem
9.	Isopropanol	Rankem
10.	Magnesium Chloride ($MgCl_2$)	Avantor
11.	Phenol	Avantor
12.	Proteinase K	Merck Millipore
13.	Sodium Chloride (NaCl)	Avantor
14.	Sodium hydroxide (NaOH) pellets	Avantor
15.	Sulfuric acid	Rankem
16.	Taq polymerase	Merck Millipore
17.	Taq polymerase buffer (1X)	Merck Millipore
18.	Tris base	Merck Millipore
19.	Tris HCl	Avantor
20.	100bp ladder	Merck Millipore
21.	2-Mercaptoethanol GR	Avantor

Appendix IV

Buffers and stock solutions

S. No.	Buffer/ stock solution	Methodology
1.	0.5M Tris Buffer (pH 8.0)	Dissolve 60.55g of tris base in 400ml of distilled water. Adjust pH to 8.0 by adding HCl and makeup the volume to 500ml with distilled water and autoclave.
2.	1.0M EDTA (Ethylenediamine tetra acetic acid)	Dissolve 186.1g of EDTA, free acid in about 200ml of distilled water. Adjust the pH to 8.0 with NaOH and make up the volume to 500ml with distilled water and autoclave.
3.	Ethidium Bromide	Stock 20mg/ml can be prepared by dissolving 1gm of ethidium bromide in 50ml of distilled water.
4.	Chloroform: Isoamyl alcohol (24:1)	Chloroform and isoamyl alcohol were mixed at 24:1 ratio and stored at room temperature.
5.	Phenol: Chloroform: Isoamyl alcohol (25:24:1)	Phenol, Chloroform and isoamyl alcohol were mixed at ratio 25:24:1 and stored at room temperature.
6.	TAE buffer (Tris / Acetate / EDTA) 50X stock solution	242g Tris base, 57.1ml Glacial acetic acid 100ml 0.5M EDTA (pH 8.0). Adjusted the pH to 8.3 with acetic acid and make up the volume to 1lit with distilled water.
7.	TE buffer (pH 8.0)	10mM Tris HCl, 1mM EDTA. 2ml of 0.5M Tris HCl pH 8.0 was mixed with 0.2ml of 0.5M EDTA, make up the volume to 100ml with sterile distil water.
8.	6X Gel loading buffer	0.25% (w/v) Bromo phenol blue, 40% (w/v) sucrose in water. Dissolve 0.25g of Bromo phenol blue was mixed with 40g of sucrose, make up the volume to 100ml with distilled water.

Appendix V

Equipments used

S. No.	Equipments	Make
1.	Electronic balance	Denver Instrument
2.	Freezer of -20^0 and -80^{0}C	Voltas
3.	Gel electrophoresis system	Mupid-exu, Takara
4.	Gel documentation system	Syngene
5.	Magnetic stirrer	Torsons
6.	Microwave oven	LG
7.	Micro centrifuge	Torsons
8.	pH meter	Torsons
9.	Power supply unit	Microtek
10.	Spectrophotometer	Systronic
11.	Thermal cycler	Bio-Rad
12.	UV- transilluminator	Syngene
13.	Vaccum centrifuge	Torsons
14.	Vortex mixer	Torsons
15.	Dry heating block	Grant Instruments
16.	Centrifuge	Thermo Scientific

Appendix-VI

ANOVA 1: Effect of acquisition access periods (AAP) by adult female whitefly, *B. tabaci* on transmission and incubation period of MYMIV in soybean plants after 24 h inoculation access period

(a) Transmission of MYMIV in soybean plants (%)

(i) First Year 2015-16

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	52934.13	10586.82	10.77	2.38
Error	54	53058.68	982.56		
Total	59	105992.8			
SEm± = 9.91			CD at 5% =28.11		

(ii) Second Year 2016-17

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	57791.61	11558.32	11.93	2.38
Error	54	52311.37	968.73		
Total	59	110102.99			
SEm± = 9.84			CD at 5% =27.91		

(iii) Pooled

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	55429.08	11085.82	23.57	2.38
Error	54	25397.92	470.33		
Total	59	80827.00			
SEm± = 6.70			CD at 5% =19.00		

(b) Disease symptom expression period (days)

(i) First Year 2015-16

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	321.75	64.35	12.15	2.38
Error	54	285.90	5.29		
Total	59	607.65			
SEm± = 0.69			CD at 5% =2.06		

(ii) Second Year 2016-17

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	436.53	87.31	19.31	2.38
Error	54	244.20	4.52		
Total	59	680.73			
SEm± = 0.65			CD at 5% =1.93		

(iii) Pooled

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	375.97	75.19	21.52	2.38
Error	54	188.68	3.49		
Total	59	564.65			
SEm± = 0.60			CD at 5% =1.70		

ANOVA 2: Effect of inoculation access periods (IAP) by adult female whitefly, *B. tabaci* on transmission and incubation period of MYMIV in soybean plants after 24 h of acquisition access period

(a) Transmission of MYMIV in soybean plants (%)

(i) First Year 2015-16

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	47453.89	9490.78	9.39	2.38
Error	54	54553.29	1010.25		
Total	59	102007.18			
SEm± = 10.05			CD at 5% =28.50		

(ii) Second Year 2016-17

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	61901.79	12380.36	15.16	2.38
Error	54	44091.02	816.50		
Total	59	105992.81			
SEm± = 9.04			CD at 5% =25.62		

(iii) Pooled

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	53867.97	10773.59	13.53	2.38
Error	54	42983.77	796.00		
Total	59	96851.74			
SEm± = 8.92			CD at 5% =25.30		

(b) Disease symptom expression period (days)

(i) First Year 2015-16

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	350.15	70.03	18.30	2.38
Error	54	206.70	3.83		
Total	59	556.85			
SEm± = 0.62			CD at 5% =1.75		

(ii) Second Year 2016-17

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	645.15	129.03	15.28	2.38
Error	54	456.10	8.45		
Total	59	1101.25			
SEm± = 0.92			CD at 5% =2.61		

(iii) Pooled

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	479.75	95.95	26.08	2.38
Error	54	198.65	3.68		
Total	59	678.40			
SEm± = 0.61			CD at 5% =1.72		

ANOVA 3: Influence of population density of viruliferous adult female whiteflies, *B. tabaci* on transmission of MYMIV in soybean plants after 24 h of acquisition and inoculation access periods

(a) Transmission of MYMIV in soybean plants (%)

(i) First Year 2015-16

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	41350.90	8270.18	9.64	2.38
Error	54	46332.93	858.02		
Total	59	87683.83			
SEm± = 9.26			CD at 5% =26.26		

(ii) Second Year 2016-17

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	59286.22	11857.24	15.87	2.38
Error	54	40354.49	747.31		
Total	59	99640.71			
SEm± = 8.64			CD at 5% =24.51		

(iii) Pooled

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	50922.93	10184.59	21.75	2.38
Error	54	25282.97	468.20		
Total	59	76205.90			
SEm± = 6.84			CD at 5% =19.40		

(b) Disease symptom expression period (days)

(i) First Year 2015-16

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	1468.40	293.68	71.24	2.38
Error	54	222.60	4.12		
Total	59	1691.00			
SEm± = 0.64			CD at 5% =1.82		

(ii) Second Year 2016-17

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	1819.73	363.95	49.38	2.38
Error	54	398.00	7.37		
Total	59	2217.73			
SEm± = 0.86			CD at 5% =2.43		

(iii) Pooled

Sources	df	SS	MS	F (cal)	F tab at 5%
Treatments	5	1618.03	323.61	98.92	2.38
Error	54	176.65	3.27		
Total	59	1794.68			
SEm± = 0.57			CD at 5% =1.62		

ABSTRACT

1. Title of the thesis

2. Student Name

Postal Address

Email and Contact No.

3. Advisor Name

Address (Office)

Email and Contact No.

4. Degree awarded

5. Year of awarded of Degree

6. Major subject

7. Total number of pages in the thesis

8. Number of words in abstract

Signature	Signature	Signature
(Dr. S.B. Das)	**(Dr. A.K. Bhowmick)**	**(Rakesh Singh Marabi)**
Advisor	Professor and Head	Student

ABSTRACT

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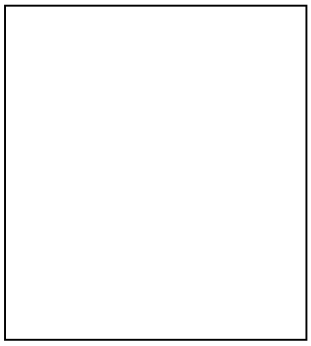

The author of this thesis **Rakesh Singh Marabi** S/o Shri P.S. Marabi was born on 1st January, 1978 in village Koilary, Anuppur District (M.P.). He passed Higher Secondary School Certificate examination from Government Higher Secondary School, Lakhaura, Anuppur (M.P.). He joined B.Sc. (Ag.) in the College of Agriculture, JNKVV, Jabalpur in 1997, and was awarded B.Sc. (Ag.) degree in 2000. The academic desire made him proceed with his post graduation in Entomology from the same institute. He has qualified ASRB NET in 2004. Further as an In-service candidate he joined for Ph.D. (Ag.) degree in Entomology Department, College of Agriculture, JNKVV, Jabalpur in the academic year 2012-13. His effort is fruitful in the form of this thesis being submitted in the partial fulfillment for the Doctoral degree with OGPA 7.33 out of 10 point scale in the year 2019.